

Gold Fields

South Deep Gold Mine

Groundwater assessment and numerical groundwater flow model for the South Deep Gold Mine Water Use License (WUL)

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Executive summary

Water Hunters was appointed by Gold Fields to undertake a groundwater assessment and numerical model update for the existing and newly drilled scavenger boreholes at South Deep Gold Mine and the Doornpoort TSF.

Aquifer testing on 28 existing boreholes and 4 new boreholes confirmed hydraulic connectivity and adequate transmissivity for sustained abstraction. Groundwater quality within the scavenger wells is characteristically poor, dominated by elevated sulphate and TDS, consistent with seepage-impacted water emanating from the TSFs.

Proposed abstraction

The proposed groundwater abstraction is 3 686 544 m³/a (10 100 m³/day) and falls under the Department of Water and Sanitation (DWS) classification of " Medium-scale abstractions (60 - 100% Recharge)".

Dewatering and Hydraulic Control

Modelled abstraction rates, 3 000 m³/day (South Deep), 4000 m³/day (Doornpoort) with potential future abstraction of 3 100 m³/day, demonstrate that the scavenger wells create a clear and sustained cone of depression, effectively lowering groundwater levels beneath the TSFs.

This hydraulic barrier significantly limits the outward movement of seepage-impacted water. The small potential baseflow (3–4 m³/day) to the unnamed tributary is negligible and indicates no material hydrological impact.

Plume Behaviour Without Scavenger Wells

If left unmitigated, the contaminant plume (SO₄ used as conservative tracer) expands 20–30 m/year, with sulphate concentrations increasing in the Leeuspruit from ~500 mg/L in 2025 to ~2 500 mg/L over the long term (2050). This represents a clear risk of downstream water quality deterioration.

Plume Behaviour With Scavenger Wells

With the scavenger wells in operation, the model indicates:

- >40% reduction in plume migration, with substantial hydraulic containment.
- Significant interception of contaminated groundwater, consistent with monitored abstraction quality.
- A reduction in sulphate loading entering the Leeuspruit (modelled decline from 2800 to 500 mg/L), confirming that scavenger wells materially reduce sulphate migration and protect downstream receptors.
- Together, these findings confirm that the scavenger-well network is a highly effective mitigation measure, both stabilising the plume and reducing long-term water quality impacts.

Scavenger well as hydraulic containment

Scavenger is deemed to provide effective hydraulic containment by reversing and flattening local gradients, intercepting seepage directly beneath and adjacent to the TSF, and

preventing plume migration into transmissive pathways. This breaks/inhibits the Source–Pathway–Receptor model by removing the hydraulic connection between the contamination source (TSF) and downstream receptors, thereby eliminating exposure and ensuring controlled management of contaminated groundwater.

Hydraulic containment through scavenger wells contributes directly to Water Conservation and Water Demand Management by preventing seepage losses, capturing and reusing groundwater within the mine’s process water circuit, reducing external freshwater abstraction, and stabilising the operational water balance. This intervention therefore not only protects groundwater quality but also reduces overall water demand and enhances water-use efficiency across the facility.

Implications for the WUL Amendment

Given the demonstrated containment efficiency, the following is justified and recommended:

- Authorised abstraction volume of 3 686 544 m³/annum to align with modelled containment requirements. This is motivated as it is Category B medium scale abstraction operation.
- Maintain and optimise the existing scavenger network to ensure ongoing plume interception and regulatory compliance.
- Routine groundwater level monitoring, quarterly quality analyses, and periodic review of abstraction rates to ensure sustainable aquifer management.
- Update the groundwater model every two years to refine predictions and assess long-term performance

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1 INTRODUCTION

Water Hunters was appointed by Gold Fields to conduct a groundwater assessment and numerical model update of the existing scavenger boreholes at South Deep Gold Mine and Doornpoort TSF, currently managed and maintained by Water Hunters as part of the over-arching water management project. This report presents the findings of a hydrogeological groundwater assessment undertaken to support the amendment of the existing Water Use License (WUL) (License no: 08/C22J/JCEFIJA/8705). The purpose of this assessment is to evaluate the potential impacts of the additional scavenger boreholes on local groundwater resources, in accordance with the requirements of the National Water Act (Act No. 36 of 1998).

This study focuses on characterizing the hydrogeological setting of the project area, assessing current groundwater conditions, and determining whether the proposed amendment, relating to an increase in abstraction will have any significant effect on groundwater availability, quality, or dependent users and ecosystems.

The assessment integrates available geological and hydrogeological information with site-specific field data including groundwater levels, pumping tests, and water quality analyses together with a numerical model that incorporates the impacts from abstraction boreholes on the groundwater regime. The data is used to develop an understanding of the groundwater system and to assess its capacity to sustain the proposed water use under both current and anticipated conditions.

1.1 Scope of Work

The following scope of work was completed:

- Aquifer testing of existing scavenger boreholes and newly drilled boreholes to determine the sustainable yields for pumping.
- Describe the existing groundwater system, including aquifer types, hydraulic properties, recharge mechanisms etc.
- Establish a baseline condition for groundwater quality and quantity prior to amendment and how the proposed amendment could influence groundwater quantity, quality, or flow patterns.
- A numerical groundwater flow model to determine the impact of the aquifer dewatering on the surrounding receptors (private borehole users, and potential drainages), and on contaminant plume migration
- Report summarising analytical findings with key conclusions and recommendations.

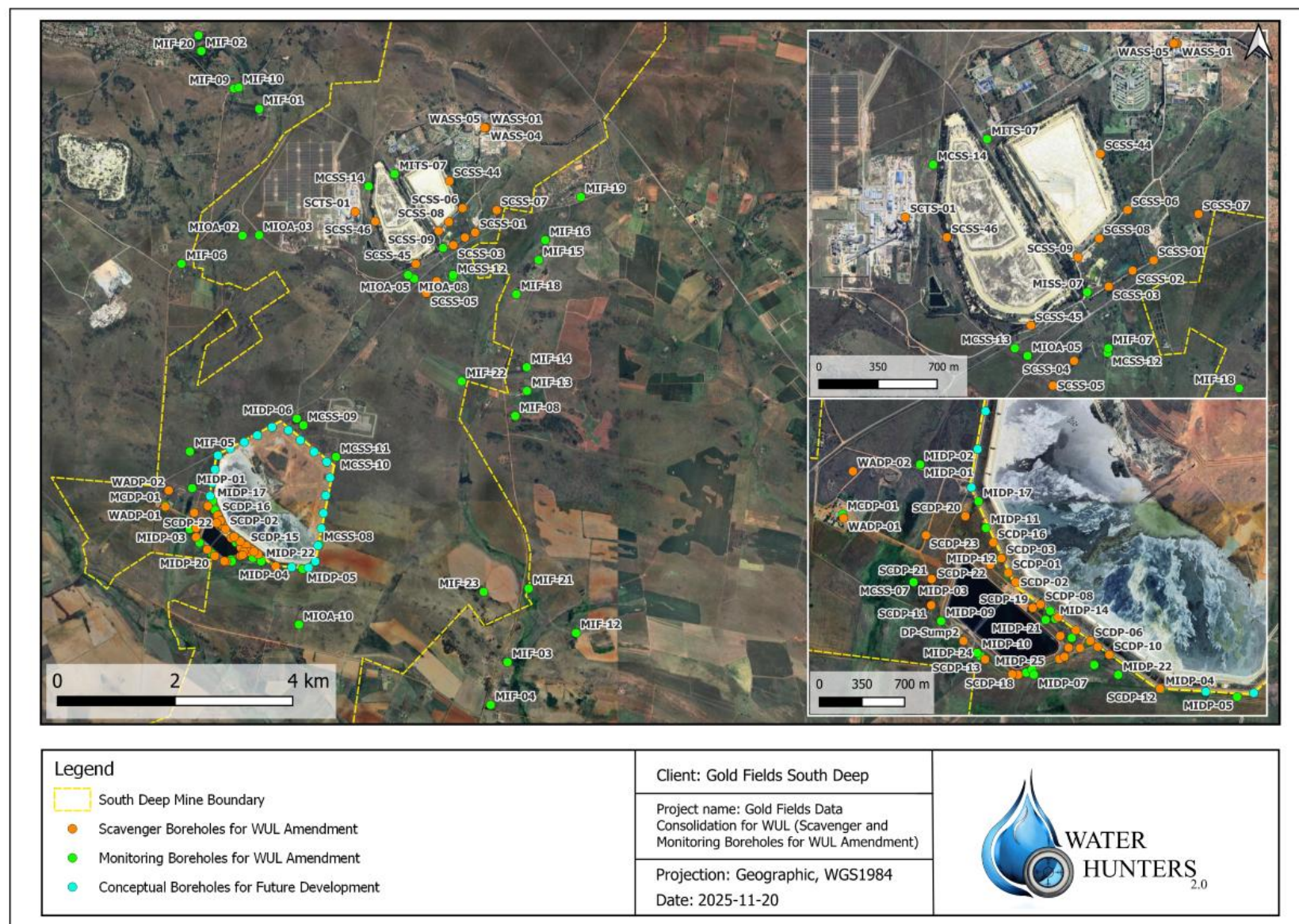


Figure 1.1 Borehole consolidation for WUL amendment

2 REGULATORY FRAMEWORK

2.1 National Water Act

The National Water Act [Act No. 36 of 1998] sets out principles for regulating water use. The water uses which require authorisation are stipulated in Section 21 of the NWA. The water uses are broadly defined as taking, storing, activities which impede stream flow, waste discharges and disposals, controlled activities, altering a watercourse, removing water found underground for certain purposes, and recreation. In general, a water use must be licensed unless it is listed in Schedule I, is an existing lawful use, is permissible under a general authorisation, or if a responsible authority waives the need for a licence. The different water use conditions are described in the bullet section below:

- Schedule I – uses are generally low volume, low impact activities that are consistent with domestic use, livestock watering, recreational use, and the use of water for emergencies. This water is permissible and does not require licensing or registration.
- Existing Lawful Use – are uses that were commenced prior to the promulgation of the NWA in 1998 and have since been registered.
- General Authorisations – is an authorisation to use water without a licence, provided that the water use is within the limits and complies with conditions set out in the Gazetted General Authorisation. The authorisation requires a registration prior to exercising the water use(s).

This groundwater assessment has been prepared in accordance with the requirements as stipulated in Annexure D of the NWA¹.

3 REGIONAL SETTING

3.1 Project Locality

South Deep Gold Mine (South Deep) is situated 45 kilometres south-west of Johannesburg, in the Gauteng Province of South Africa (Figure 3.1). South Deep Gold Mine is an underground mining operation with two shaft systems and a metallurgical plant. The South Shaft complex operates to a depth of 2 650 metres below surface and the Twin Shaft complex operates to a depth of 2 995 metres below surface.

3.2 Topography and Drainage

The area under study is in quaternary catchment C22J in the Upper Vaal Management Area (WMA). The area is characterised by gently undulating topography, sloping from 1660 mamsl in the North to 1540 mamsl in the South near the Doornpoort TSF.

¹ National Water Act, 1998 (Act No. 36 of 1998): Regulations regarding the procedural requirements for Water Use Licence Applications and Appeals

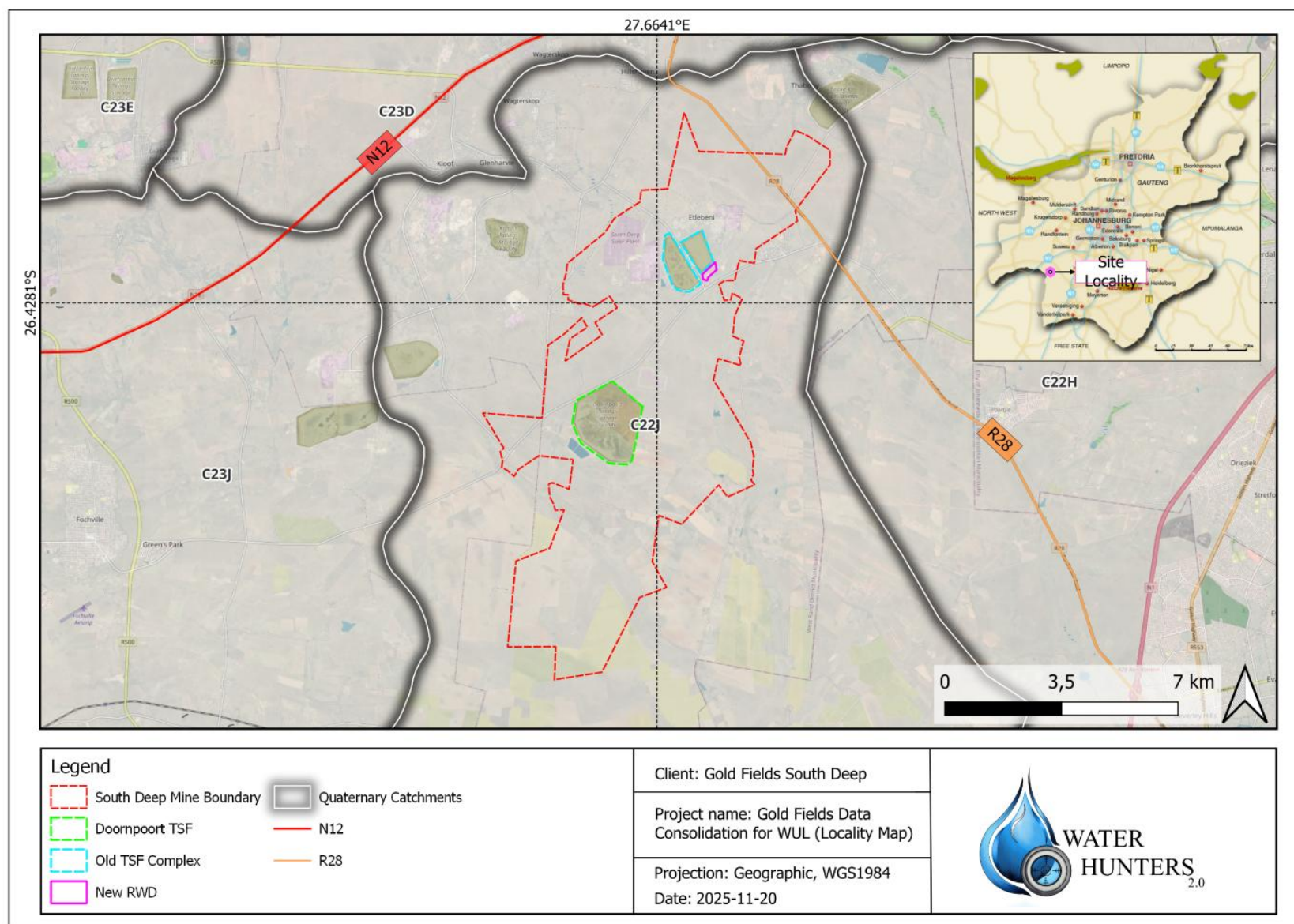


Figure 3.1 Project locality

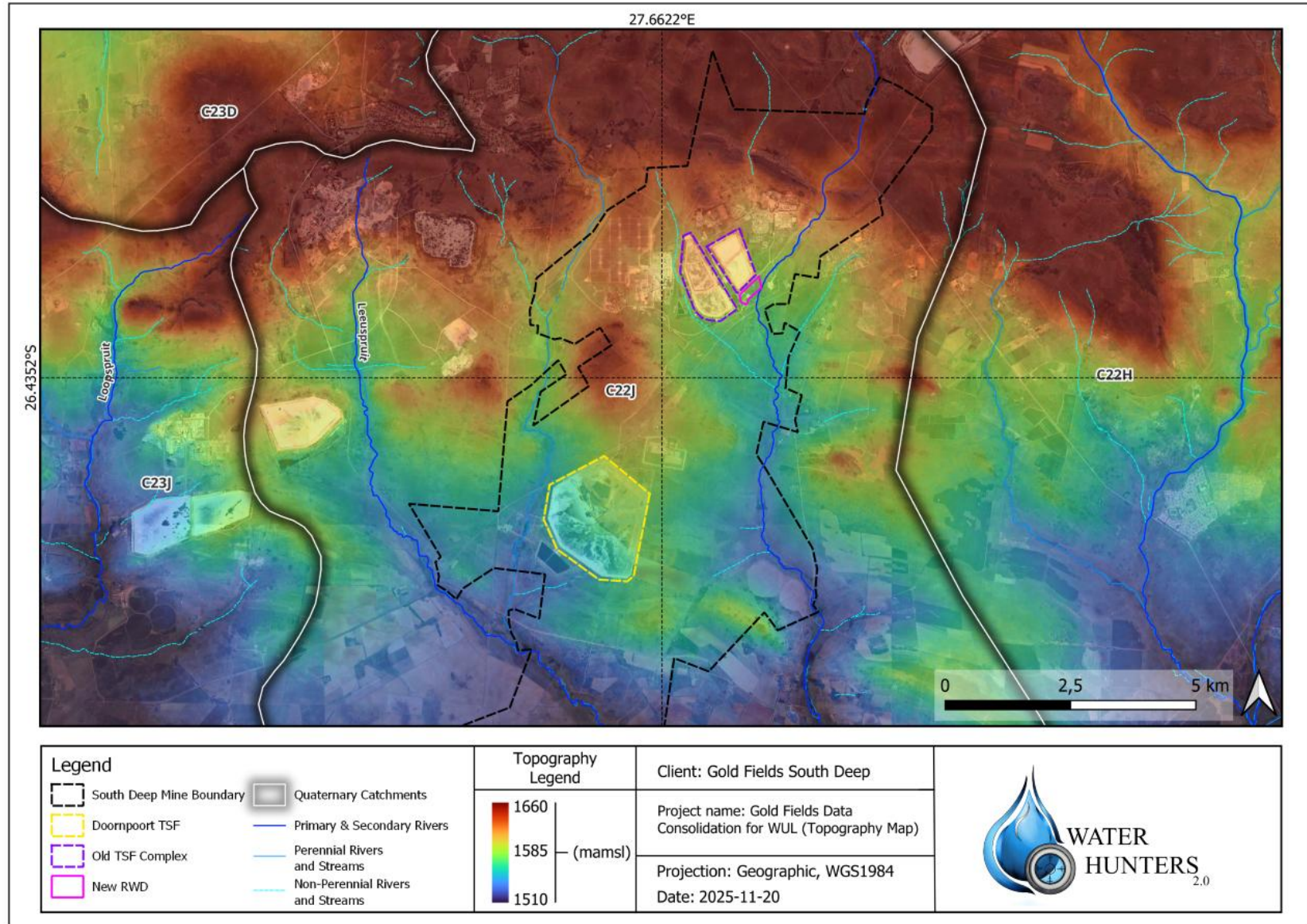


Figure 3.2 Topography and drainage

4 HYDROGEOLOGICAL CONTEXT

4.1 Geology

Regionally the South deep mine is underlain by rocks of the Pretoria Group from the Transvaal Super-Group (Figure 4.1). The Doornpoort TSF is underlain by a geological contact between the Hekpoort andesite and Strubenkop shale and quartzite. The Old TSF area is underlain by the Timeball Hill formation which consists of ferrogenous shale and hornfels of the Pretoria Group (Figure 4.1). An E-W trending diabase dyke crosscuts below the Old TSF area.

4.2 Hydrogeology

The hydrogeological map series of South Africa indicates that the area falls within the d2: Intergranular and Fractured Type Aquifer with average borehole yields (0.1 – 0.5 l/s) (Figure 4.2). Regionally there are three different aquifer systems in the area which developed from the Pretoria group.

4.2.1 Upper regolith (unsaturated zone)

The upper regolith comprises a relatively thin soil and transported cover underlain by a variably weathered bedrock profile developed on the Karoo / Transvaal / Witwatersrand succession above the deep mining horizons. Regionally, the weathered zone in the Far West Rand / South Deep area is typically on the order of 5–10 m thick, with shallow saprolitic and fractured bedrock aquifers hosted within this profile before grading into fresher, more competent rock at depth. With depth, the regolith grades into partially weathered, fractured rock forming the shallow bedrock aquifer. This marks the transition from dominantly vadose to saturated conditions; the water table typically occurs within the lower regolith to upper fractured zone, depending on topography, dewatering and local recharge. Effective porosity is estimated to be in the range of 5 to 15%.

4.2.2 Shallow weathered aquifer

Situated within the weathered formation because of increasing secondary porosity, 5-30 metres below ground level (mbgl), limited and variable in extent.

4.2.3 Deeper semi-confined fractured zone aquifer

Situated below the weathered aquifer and expected to be hydraulically connected to the overlying weathered aquifer due to the absence of consistent confining and impermeable zones (aquitards) within the weathered formations. Based on existing information the fractured aquifer extends to a depth of approximately 60 to 100 m.

4.2.4 Deeper confined compartmentalised dolomitic (karst) aquifer

This aquifer is associated with the deep confined compartmentalised dolomitic (karst) lithology. It underlies a thick succession of impermeable dolerite, shale and lava, some 400 m in thickness.

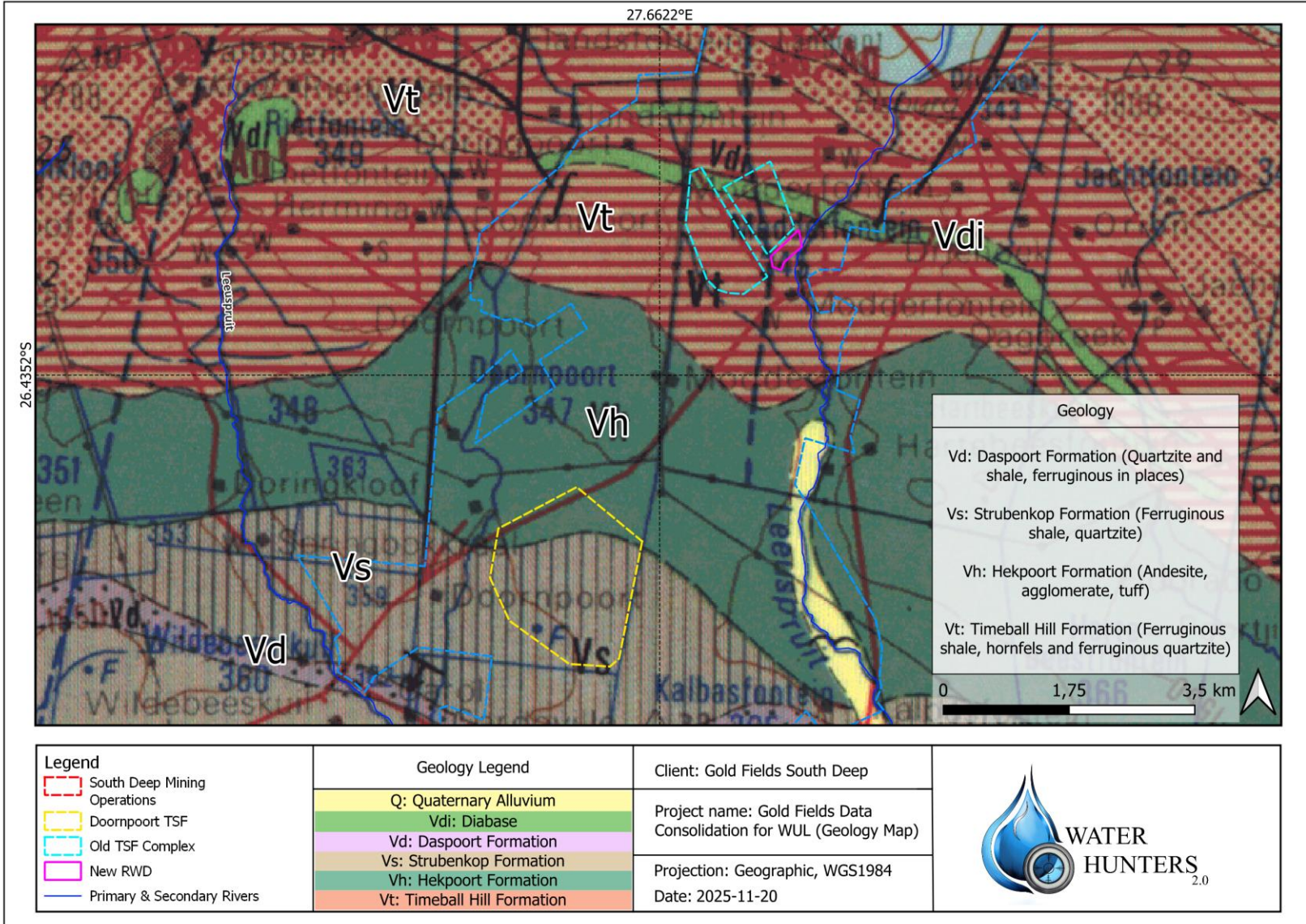


Figure 4.1 Geological map of the study area

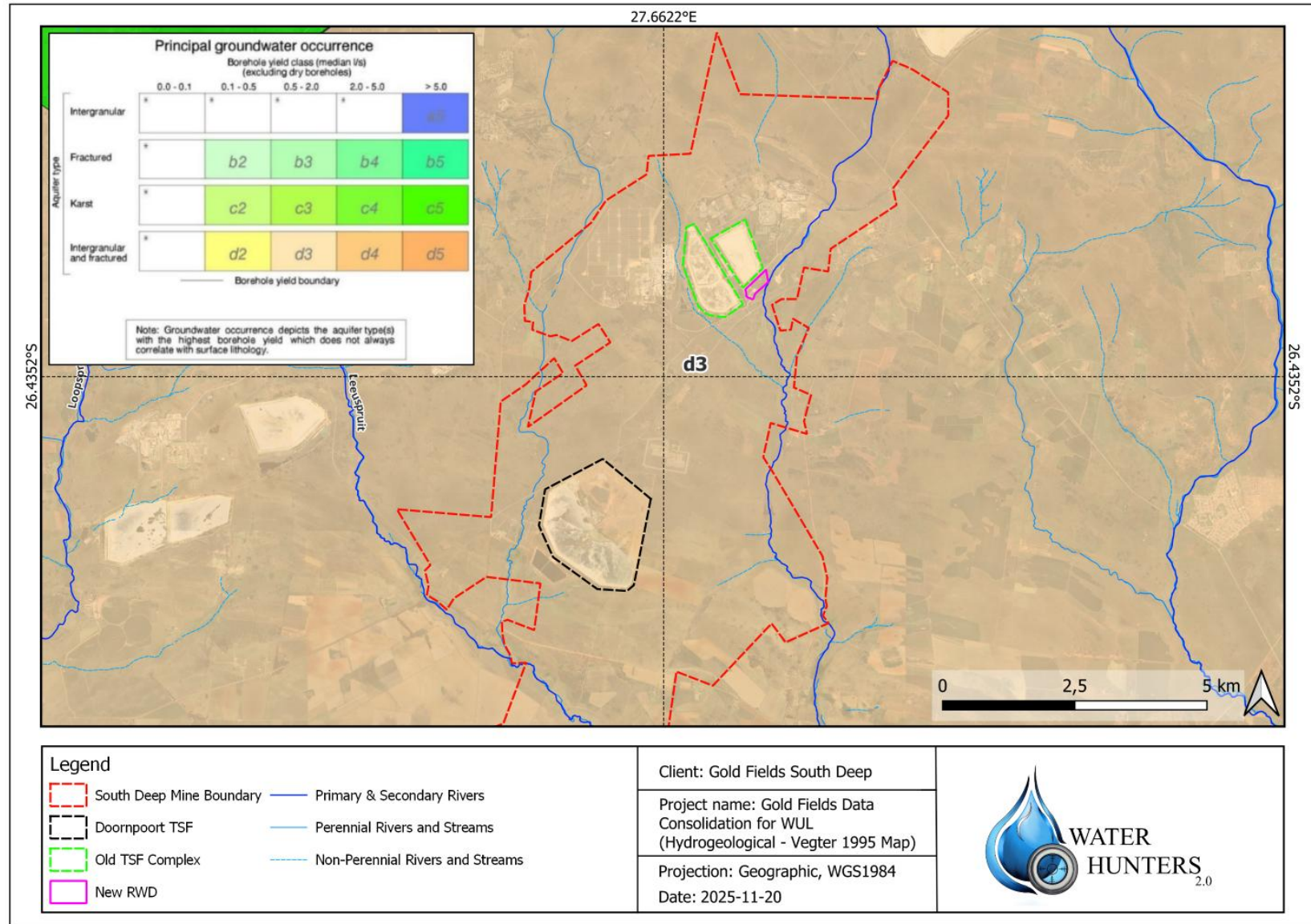


Figure 4.2 Hydrogeological classification map (Vegter, 1995)

5 FIELD INVESTIGATION

Water Hunters conducted an extensive hydrogeological field investigation inclusive of aquifer testing of the existing scavenger boreholes to determine the yield potential and the subsequent sustainable pumping yields. The details of the aquifer tests are described in the sections below.

5.1 Aquifer Testing

Water Hunters conducted an aquifer testing programme on 28 existing boreholes (25 existing scavenger boreholes and 3 existing monitoring boreholes) and 4 newly drilled boreholes.

- The existing scavenger boreholes were aquifer tested using the existing equipment and VSD's installed in the boreholes to determine the hydrogeological properties of the groundwater system and the sustainable yields of the boreholes.
- The three (3) monitoring boreholes were tested by means of a pump test rig. The details of the aquifer testing programme are summarized in Table 5-1.

5.1.1 Step Test

A step-drawdown test is a single well test that is frequently conducted after drilling to determine well efficiency. The step drawdown is pumped at a low constant discharge rate until drawdown within the well stabilises (Kruseman & de Ridder, 1994). The pumping rate is then increased to a higher constant-discharge rate until the drawdown stabilizes once more (Kruseman & de Ridder, 1994).

- 30 min Step tests were conducted on the boreholes with details summarised in Table 5-1.
- The step tests were used to determine the rate at which the constant rates should be conducted.
- The step test performed on SDS05, SD10, SC40 and SC67 showed that the boreholes had a very low yield and was excluded from the constant rate testing.

5.1.2 Constant Rate

A constant rate pump test is conducted by pumping a well at a constant rate while monitoring the drawdown occurring in the borehole (or in an observation borehole). At the conclusion of pumping, the recovery of water levels in the borehole is measured.

Eight-hour constant rate tests were conducted on the boreholes where the step tests were successful. Observations made during the constant rate tests of the 24 scavenger boreholes are summarised in Table 5-1.

5.1.3 Recovery Tests

After the Constant Rate Test (CRT) groundwater level recovery was monitored (residual drawdown) within the boreholes. Measuring residual drawdown is conducted until groundwater levels are within 90% of pre constant rate test. Prior to the commencement of the test pumping programme static groundwater levels were measured in the boreholes to allow drawdown calculations during test pumping.

Table 5-1 Summary of the aquifer testing programme

	Borehole_ID	Latitude	Longitude	Borehole Depth (mbgl)	Static Water level (mbgl)	Pump size	Step Test				Constant Rate Test			Comments
							No. of Steps	Duration (min)	Yield (L/s)	Drawdown obtained (m)	Duration (min)	Yield (L/s)	Water level end of CDT (mbgl)	
OLD RWD Scav Wells	SCSS-03	-26.42232	27.680079	60	2.16	4.0 kW	3	30	2	3.44	480	3	5.32	
								30	3	4.33				
								30	3.4	4.84				
	SCSS-02	-26.42115	27.682049	60	0.94	5.5 kW	3	30	2	4.68	480	4	12.45	
								30	4	11.21				
								60	5.5	18.58				
	SCSS-01	-26.42039	27.683782	60	2.3	5.5 kW	4	30	2.5	4.14	480	4.5	6.37	
								30	3.5	4.98				
								30	4.5	6				
								30	6.1	8.13				
	SCSS-04	-26.42781	27.67723	52	8.04	5.5 kW	3	30	2	10.92	480	3	15.08	
								30	3	13.18				
								30	3.34	14.28				
	SCSS-05	-26.42963	27.67548	41.3	1.95	4.0 kW	4	30	1	2.75	480	4	9.36	
								30	2	3.73				
								30	3	5.02				
								30	4.5	6.99				
	SCSS-08	-26.41878	27.679306	60	12.2	-	3	30	2.5	22.04	480	3.2	28	
								30	3	25.15				
								30	3.5	28.85				
	SCSS-07	-26.41697	27.687472	101	3.3	4.0 kW	3	30	1	9.79	480	2	20.47	
								30	3	30.21				
								30	3.7	38.87				
	SCSS-06	-26.41667	27.681639	100	7.65	4.0 kW	3	30	1.5	12.34	480	1.3	10.91	
								30	2.5	18.23				
								10	3.5	21.42				
Doornpoort TSF Scavenger Boreholes	SCDP-11	-26.46692	27.63621	30	1.86	1.5 kW	3	30	0.1	2.08	480	0.5	4.4	
								30	0.5	4.33				
								30	1	22.08				
	SCDP-12	-26.47136	27.64980	35	0.28	1.5 kW	3	30	0.1	0.66	480	0.2	8.71	
								30	0.3	6.16				
								60	0.4	21.27				
	SCDP-01	-26.46519	27.64079	25	4.82	5.5 kW	-	-	-	-	480	8	15.31	
	SCDP-13	-26.49800	27.63941	30	1.13	1.5 kW	2	30	0.2	12.04				Too weak for CDT
								20	0.4	28.63				
	SCDP-06	-26.46881	27.64567	29	0.83	1.5 kW	2	30	1.5	6.55	480	2.57	13.1	
								30	2.5	12.72				
	SCDP-19	-26.46705	27.64224	18	2.43	1.5 kW	5	30	0.5	3.42	480	1.5	6.74	
								30	1	4.81				
								30	1.5	6.45				
								30	2	8.47				
								30	3.1	18				
	SCDP-14	-26.46855	27.64388	18	4.21	-	3	30	0.3	7	420	0.5	10.35	

	Borehole_ID	Latitude	Longitude	Borehole Depth (mbgl)	Static Water level (mbgl)	Pump size	Step Test				Constant Rate Test			Comments
							No. of Steps	Duration (min)	Yield (L/s)	Drawdown obtained (m)	Duration (min)	Yield (L/s)	Water level end of CDT (mbgl)	
								30	0.6	11.96				
								15	0.9	17				
	SCDP-15	-26.46825	27.64480	30	2.67	1.5 kW	4	60	30	0.2	480	0.7	8.8	
								60	30	0.3				
								60	30	0.4				
								60	30	1.5				
								60	30	1.5				
	SCDP-10	-26.46955	27.64679	30	0	1.5 kW	4	30	0.1	0.21	480	0.5	7.2	
								30	0.8	12.13				
								30	1	21.72				
								10	1.2	28.37				
	SCDP-16	-26.46358	27.63990	45	2.24	1.5 kW	4	30	0.3	7.37	480	0.35	8.26	
								30	0.6	13.7				
								30	0.9	22.38				
								30	1.2	35.8				
	SCDP-03	-26.46442	27.64043	-	-	-	-	-	-	-	-	-	-	Not tested
	SCDP-09	-26.46756	27.64374	40	2.1	1.5 kW	3	30	0.5	4.56	300	1.1	10.45	
								30	1	8.22				
								60	1.2	10.08				
	SCDP-08	-26.46687	27.64270	60	3.27	1.5 kW	4	30	0.5	5.7	480	1.4	15.18	
								30	1	9.91				
								30	1.5	16.38				
								60	1.7	20.13				
	SCDP-02	-26.46569	27.64122	40	4.51	-	4	60	-	-	480	4.3	10.13	
								60	-	-				
								60	-	-				
								60	-	-				
	SCDP-07	-26.46920	27.64504	40	0.93	1.5 kW	3	30	1	5.2	480	1.6	9.17	
								30	1.5	8.23				
								30	1.6	9.01				
	SCDP-18	-26.47062	27.64138	-	-	-	-	-	-	-	-	-	-	Too weak for testing
	SCDP-05	-26.46977	27.64382	40	0	1.5 kW	2	60	2	5.26	480	3	9.66	
								60	3	9.24				
	SCDP-04	-26.46917	27.64437	40	1.26	1.5 kW	3	30	1.5	2.94	480	5	11.83	
								30	2	3.81				
								60	5	11.42				
Monitoring	SD10	-26.42443	27.676246	16.9	6.74	-	1	3	0.5	15	-	-	-	Too weak for CDT
	SDS04	-26.42584	27.673303	76.4	4.99	-	3	30	0.5	8.36	480	0.7	13.12	
								30	1	14.2				
								50	2	60				
	SDS05	-26.42456	27.675815	79.1	7.05	-	3	30	0.5	30.75	-	-	-	Too weak for CDT
								30	0.7	70.12				
								2	1	79				

5.2 Sustainable Yields

The sustainable yields of the pump tested boreholes were calculated using the FC (Flow Characteristic) Method. The FC Method is a Microsoft Excel based program, which uses different aquifer solutions to determine a risk-based sustainable yield for the boreholes. The method is based on a worst-case scenario and calculates the recommended sustainable yield as if the borehole is pumped continuously at the recommended rate for a two-year period without recharge to the aquifer system. The calculated borehole sustainable yields are summarized in Table 5-2.

It is important to note that there are limitations in predicting the aquifers response to long-term abstraction. Because of this limitation it is strongly recommended that a borehole management plan is put into place to monitor and evaluate the drawdown levels of the production boreholes on a regular basis (monthly) to prevent undesirable dewatering of the aquifer. With long-term abstraction records and groundwater level monitoring, the recommended abstraction rates can be adjusted with a higher degree of accuracy.

Table 5-2 Summary of sustainable yields calculated from aquifer tests

Borehole ID	Coordinates		Sustainable Yield (24 hrs/day)			Comments
	Latitude	Longitude	Recommended yield (L/s)	Pumping cycle (hr)	Abstraction in pumping cycle (m ³)	
SCSS-03	-26.4223	27.6801	4.83	24	417.31	
SCSS-02	-26.4211	27.6820	3.7	24	319.68	
SCSS-01	-26.4204	27.6838	6.7	24	578.88	
SCSS-04	-26.4278	27.6772	2.41	24	208.22	
SCSS-05	-26.4296	27.6755	3.97	24	343.01	
SCSS-08	-26.4188	27.6793	1.9	24	164.16	
SCSS-07	-26.4170	27.6875	1.39	24	120.10	
SCSS-06	-26.4167	27.6816	1.19	24	102.82	
SCDP-11	-26.4669	27.6362	0.5	24	43.20	
SCDP-12	-26.4714	27.6498	0.2	24	17.28	
SCDP-01	-26.4652	27.6408	7.43	24	641.95	
SCDP-13	-26.4980	27.6394				No CDT
SCDP-06	-26.4688	27.6457	2.33	24	201.31	
SCDP-19	-26.4671	27.6422	2.27	24	196.13	
SCDP-14	-26.4685	27.6439	0.52	24	44.93	
SCDP-15	-26.4682	27.6448	0.85	24	73.44	
SCDP-10	-26.4696	27.6468	0.63	24	54.43	
SCDP-16	-26.4636	27.6399	0.44	24	38.02	
SCDP-03	-26.4644	27.6404				Not tested, motor faulty
SCDP-09	-26.4676	27.6437	1.36	24	117.50	
SCDP-08	-26.4669	27.6427	1.17	24	101.09	
SCDP-02	-26.4657	27.6412	4.57	24	394.85	
SCDP-07	-26.4692	27.6450	1.91	24	165.02	

Borehole ID	Coordinates		Sustainable Yield (24 hrs/day)			Comments
	Latitude	Longitude	Recommended yield (L/s)	Pumping cycle (hr)	Abstraction in pumping cycle (m ³)	
SCDP-18	-26.4706	27.6414				Not fully tested, Insufficient yield
SCDP-05	-26.4698	27.6438	3.35	24	289.44	
SCDP-04	-26.4692	27.6444	4.67	24	403.49	
SDS04	-26.4258	27.6733	0.58	24	50.11	
SCDP-21	-26.46552	27.63624	2.5	24	216.00	
SCDP-22	-26.46476	27.63972	1	24	86.40	
SCDP-23	-26.4632	27.6359	3	24	259.20	
SCSS-09	-26.42015	27.67755	3	24	259.20	
Total abstraction (24 hrs/day):					5 907.17	

5.3 Spatial Distribution of calculated sustainable yields

A map indicating the spatial distribution of the proposed sustainable yields is illustrated in Figure 5.2. Sustainable yield and hydraulic conductivities decrease away from the north-western embankment/RWD corner, where the most transmissive fracture network is developed. The Doornpoort wellfield therefore consists of:

- A core high-yield, high-K production cluster (SCDP-01, -02, -19),
- Moderate yields along the western and southern TSF walls, and
- Low-yield, land conductivities and localised pockets notably to the south-east and at some northern points).

Table 5-3 Simulated annual abstraction from current and future abstraction boreholes and sumps

New ID	Latitude (Y)	Longitude (X)	Yield (m3/day)	Yield (m3/Year)
SCDP-11	-26.46692	27.63621	30	10800
SCDP-12	-26.47136	27.64980	30	10800
SCDP-06	-26.46881	27.64567	335	120600
SCDP-13	-26.46980	27.63941	200	72000
SCDP-01	-26.46519	27.64079	580	208800
SCDP-19	-26.46705	27.64224	115	41400
SCDP-14	-26.46855	27.64388	135	48600
SCDP-15	-26.46825	27.64480	120	43200
SCDP-10	-26.46955	27.64679	64	23040
SCDP-16	-26.46358	27.63990	80	28800
SCDP-03	-26.46442	27.64043	500	180000
SCDP-17	-26.46442	27.64038	200	72000
SCDP-09	-26.46756	27.64374	122	43920
SCDP-08	-26.46687	27.64270	105	37800
SCDP-02	-26.46569	27.64122	504	181440
SCDP-07	-26.46920	27.64504	168	60480
SCDP-18	-26.47062	27.64138	15	5400
SCDP-05	-26.46977	27.64382	520	187200
SCDP-04	-26.46917	27.64437	310	111600
SCDP-20	-26.46218	27.63824	130	46800
SCDP-21	-26.46552	27.63624	130	46800
SCDP-22	-26.46476	27.63972	86.4	31104
SCDP-23	-26.46319	27.63590	259	93240
WADP-01	-26.46228	27.63100	86.4	31104
WADP-02	-26.45979	27.63156	86.4	31104
DP-Sump1	-26.47059	27.64103	30	10800
DP-Sump2	-26.46882	27.63813	30	10800
DP-Sump3	-26.46966	27.64413	30	10800
DP-Sump4	-26.46912	27.64610	30	10800
SCSS-03	-26.42232	27.68008	575	207000
SCSS-02	-26.42115	27.68205	930	334800
SCSS-01	-26.42039	27.68378	640	230400
SCSS-04	-26.42781	27.67723	320	115200
SCSS-05	-26.42963	27.67548	310	111600
SCSS-08	-26.41878	27.67931	620	223200
SCSS-07	-26.41467	27.68833	370	133200
SCSS-06	-26.41667	27.68164	710	255600
SCSS-09	-26.42015	27.67755	259	93240
SCTS-01	-26.41720	27.66333	86.4	31104
WASS-01	-26.40437	27.68571	129.6	46656
WASS-04	-26.40436	27.68558	129.6	46656

New ID	Latitude (Y)	Longitude (X)	Yield (m3/day)	Yield (m3/Year)
WASS-05	-26.40438	27.68542	129.6	46656
TOTAL				3686544

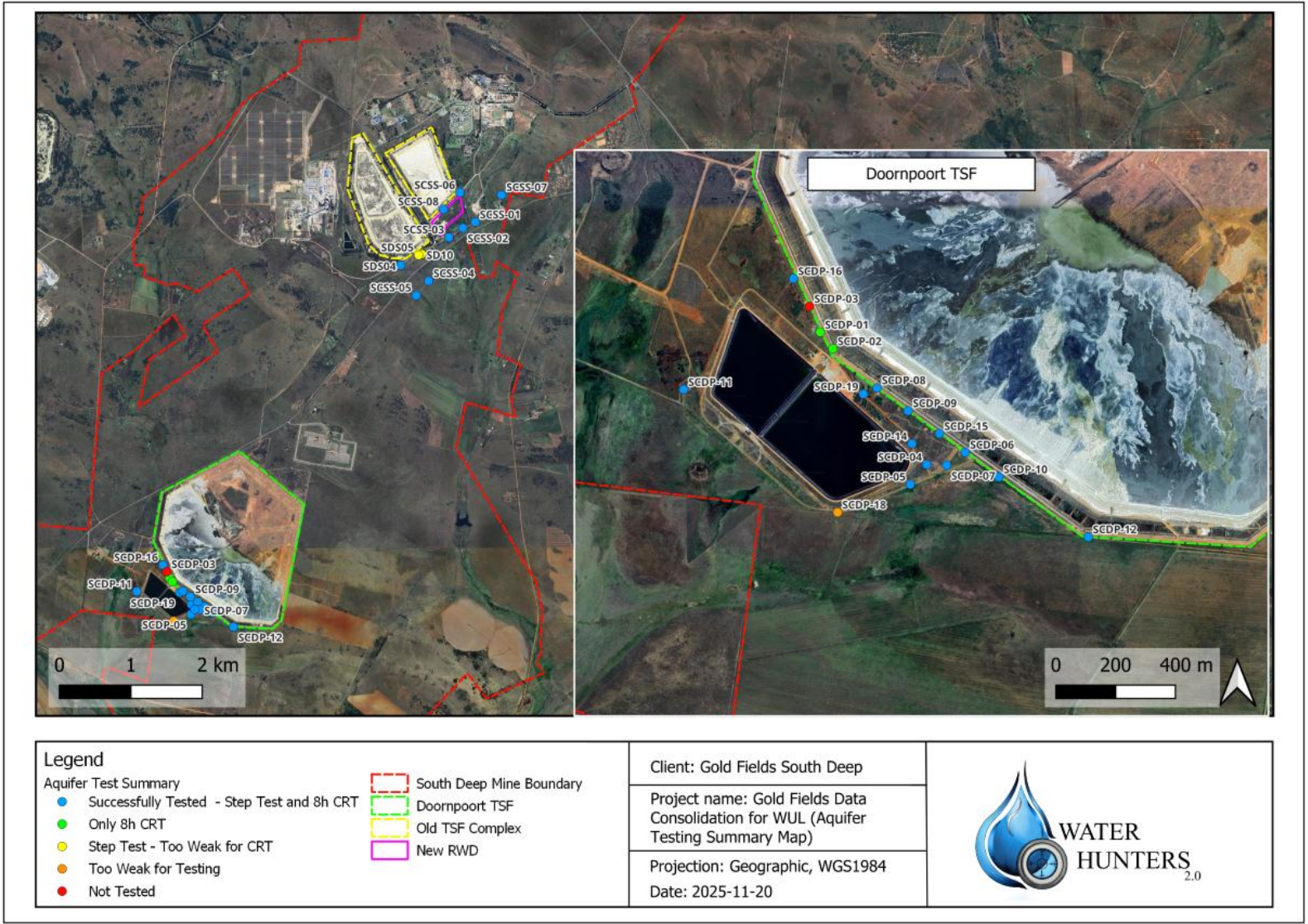


Figure 5.1 Positioning of aquifer tested boreholes

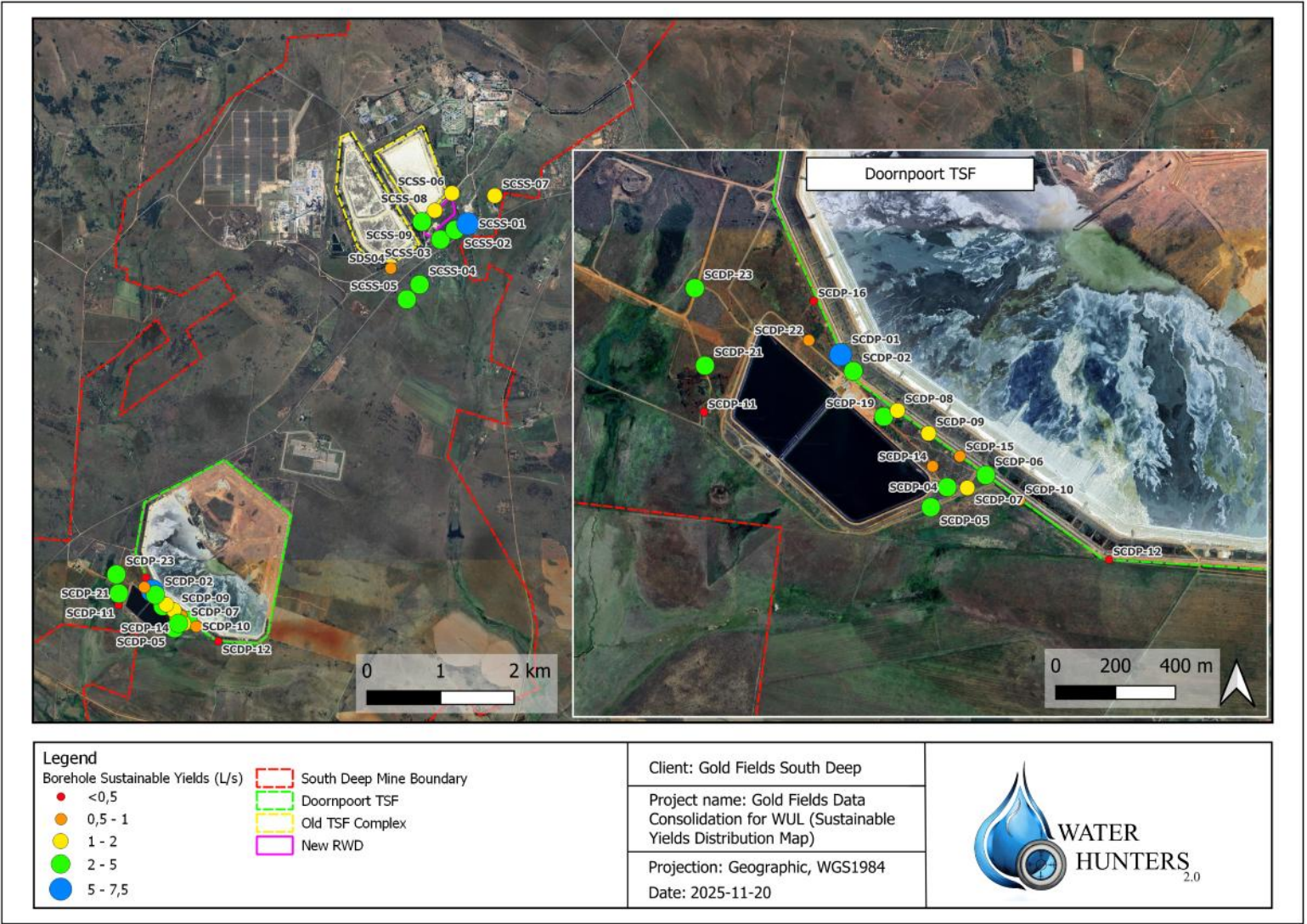


Figure 5.2 Spatial distribution of calculated sustainable yields

5.4 Calculated hydraulic conductivities

Using the flow characteristic method the hydraulic conductivity could be derived from the aquifer tested boreholes (see. Hydraulic conductivity values for the Doornpoort TSF boreholes were calculated using the Cooper–Jacob approximation of the Theis analytical solution, applied to the constant-rate test (CRT) data. For each borehole, the sustained pumping rate (Q), measured drawdown at the end of the CRT (s), and effective saturated thickness (b) were used to derive transmissivity (T)

Application of this method shows that the Doornpoort TSF wellfield is characterised by generally low aquifer permeability, with hydraulic conductivities ranging from 0.07 to 4 m/day (equivalent to 1×10^{-6} to 5×10^{-5} m/s). The highest K values occur in SCDP-01, SCDP-19 and SCDP-02, followed by intermediate responses in SCDP-04, SCDP-06 and SCDP-11, indicating the presence of discrete, locally enhanced fracture zones capable of moderate abstraction. In contrast, boreholes such as SCDP-12, SCDP-16 and SDS04 yielded very low K values and poor specific capacities, confirming that they intersect low-transmissivity weathered material where long-term abstraction is not feasible.

Overall, the results demonstrate a heterogeneous, predominantly low-permeability aquifer, with only a few preferential flow zones contributing meaningfully to groundwater movement and scavenger well performance.

Table 5-4 Calculated hydraulic conductivities

Borehole ID	Q (L/s)	Drawdown s (m)	Saturated thickness b (m)	K (m/s)	K (m/day)
SCSS-03	3	3.16	57.8	0.0000199	1.72
SCSS-02	4	11.51	59.1	0.00000712	0.62
SCSS-01	4.5	4.07	57.7	0.0000232	2
SCSS-04	3	7.04	44	0.0000117	1.01
SCSS-05	4	7.41	39.3	0.0000166	1.43
SCSS-08	3.2	15.8	47.8	0.00000513	0.44
SCSS-07	2	17.17	97.7	0.00000144	0.12
SCSS-06	1.3	3.26	92.4	0.00000522	0.45
SCDP-11	0.5	2.54	28.1	0.00000846	0.73
SCDP-12	0.2	8.43	34.7	8.27E-07	0.07
SCDP-01	8	10.49	20.2	0.0000457	3.95
SCDP-06	2.57	12.27	28.2	0.00000899	0.78
SCDP-19	1.5	4.31	15.6	0.000027	2.34
SCDP-14	0.5	6.14	13.8	0.00000714	0.62
SCDP-15	0.7	6.13	27.3	0.00000505	0.44
SCDP-10	0.5	7.2	30	0.0000028	0.24
SCDP-16	0.35	6.02	42.8	0.00000164	0.14
SCDP-09	1.1	8.35	37.9	0.0000042	0.36
SCDP-08	1.4	11.91	56.7	0.00000251	0.22
SCDP-02	4.3	5.62	35.5	0.0000261	2.25
SCDP-07	1.6	8.24	39.1	0.00000601	0.52
SCDP-05	3	9.66	40	0.00000939	0.81
SCDP-04	5	10.57	38.7	0.0000148	1.28
SDS04	0.7	8.13	71.4	0.00000146	0.13
Median	1.80	7.77	39.20	0.00000713	0.62

5.5 Water Quality Analysis

Twenty-four (24) water quality samples were collected from the boreholes during the eight-hour tests and sent to Environmental Pollution Laboratory (EPL) which is a SANAS accredited Laboratory.

The groundwater chemistry is compared to the SANS 241 (2015) specifications for drinking water. Concentrations that exceed the SANS 241 guideline limits are highlighted in red. The borehole water quality is also compared to the South African Water Quality Guidelines Volume 4: Agricultural Use: Irrigation and Volume 5: Agricultural Use: Livestock Watering (DWAF, 1996). The following observations are made in terms of the hydrochemistry:

- The pH values from the groundwater samples for the scavenger wells are circum-neutral, with a range of 6.4 and 7.5.
- The groundwater is moderately saline, with all samples measuring Electrical conductivity (Ec) values above the DWS Irrigation limit (< 40 mS/m) and 21 of the 24 samples exceeding the SANS 241 limit of 170 mS/m. The main contributing ions to the salinity are bicarbonate alkalinity, magnesium, sodium and to some extent chloride.

- The most notable consistent exceedances and element of concern is Sulphate (SO₄). Factors contributing to the elevated Sulphate (SO₄) in groundwater are mainly mining activities with runoff and seepage from the Tailings Storage Facilities (TSF's). The groundwater from all boreholes are therefore **not fit for human consumption**.
- Boreholes which recorded both elevated sulphate and manganese concentrations are SCSS-03, SCSS-07, SCSS-02, SCSS-01, SCSS-06 and SCSS-08

Table 5-5: Hydrochemistry Results for boreholes tested at Gold Fields

Sample ID	Unit	SANS 241	DWS Irrigatio n 1996	DWS Livestock	Gold Fields																							
					SCDP -01	SCDP -02	SCDP -07	SCDP -05	SCSS- 04	SCSS- 03	SCSS- 07	SCDP -12	SCDP -06	SCDP -10	SCDP -19	SCSS- 02	SCSS- 01	SCDP -11	SCDP -16	SCSS- 05	SCSS- 06	SCDP -14	SCDP -04	SDS04	SCSS- 08	SCDP -15	SCDP -09	SCDP -08
Date																												
pH	pH	<5 & >9.7	<6.5 & >8.4	NG	7.28	7.14	7.21	7.3	7.27	7.1	6.9	6.89	6.8	7.15	7.41	7.12	6.86	7.32	7.04	7.53	7.35	7.22	7.07	7.57	6.47	7.42	7.35	7.27
EC	mS/m	170	40	NG	375	369	315	281	230.1	292.4	144.8	221.4	318	284.3	359	325	132.3	234.3	374	212.9	117.9	272.5	266.1	200.4	233.6	288.2	318.2	340.2
TDS	mg/ℓ	1200	NG	<1000	3868	4004	3080	2622	2873	2851	1282	1904	3146	2550	3380	2919	1005	2085	3617	1803	954	2537	2497	1620	2104	2650	3002	3318
Total Alkalinity	CaCO ₃	NG	NG	NG	98.1	115	93.2	116.4	137	135.7	99.56	106.7	74.26	153.8	126	164.9	103.4	72.87	89.67	164.7	111.5	129.9	60	134.1	63.33	115.2	137.7	133.5
P-Alk	CaCO ₃	NG	NG	NG	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.06	<0.6	<0.6	<0.6	<0.6	
Chloride	mg/ℓ Cl	300	100	<1500	270.3	250.6	270.1	236.4	162.8	154.2	69.24	215.9	282.7	256.3	228.5	178.9	72.76	163	275.1	117.6	64.1	235.4	305.2	151.8	131.1	236.9	234.6	240.4
Sulphate	mg/ℓ SO ₄	500	NG	<1000	2186	1983	1670	1450	1172	1628	686.1	922.6	1703	1409	1771	1675	516.4	1175	1903	902.7	501.3	1364	1312	839.9	1122	1539	1749	1924
Fluoride	mg/ℓ F	<1.5	NG	NG	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	0.07	<0.05	<0.05	0.07	0.07	<0.05	0.06	<0.05
Nitrate as N	mg/ℓ N	11	5	100	<0.5	<0.5	<0.5	1.07	<0.5	<0.5	1.16	1.12	<0.5	1.11	<0.05	1.65	0.76	2.05	<0.5	<0.5	<0.5	<0.5	1.18	3.52	<0.5	<0.5	<0.5	<0.5
Calcium	mg/ℓ Ca		NG	<1000	526.1	456.8	419.7	378.2	334.1	486.5	183.1	256	469.1	370	466.4	449.4	136.1	299.5	520.9	339.7	156.4	0	0	0	0	428.7	455.3	480
Magnesium	mg/ℓ Mg		NG	<500	307.1	263.8	216.6	185.7	179.1	123	87.89	161.1	226.7	203.9	255.9	123.5	67.31	159.8	256.2	103.1	69.52	176.5	171	66.73	138.2	202.9	239.8	272.2
Sodium	mg/ℓ Na	<200	70	<2000	92.57	74.84	49.43	49.74	43.06	94.19	30.53	46.91	47.31	63.86	57.76	159.4	60.21	41.37	91.82	46.81	13.9	44.99	42.75	55.63	36.07	51.97	54.56	71.21
Potassium	mg/ℓ K		NG	NG	5.03	5.25	5.78	4.83	4.78	2.83	1.17	5.88	5.74	5.12	5.12	4.56	2.28	3.29	4.05	1.33	0.54	3.91	4.09	1.49	2.06	4.73	5.18	5.55
Al	mg/ℓ Al	0.3	5	<5	0.32	0.11	0.15	0.12	0.13	0.25	0.19	0.11	<0.05	<0.05	0.09	0.09	0.06	0.07	0.18	0.15	0.09	0.09	0.14	<0.05	0.13	0.08	0.11	0.14
Arsenic	mg/ℓ As	≤0.01			<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	0.01
Iron	mg/ℓ Fe	2	5	<10	0.23	0.15	0.23	0.06	0.1	0.09	1.59	0.66	0.11	<0.05	0.21	0.11	0.06	0.09	1.07	0.1	0.72	0.08	<0.05	0.07	0.12	0.38	0.67	0.48
Manganese	mg/ℓ Mn	0.4	0.02	<10	<0.05	<0.05	<0.05	<0.05	<0.05	6.37	1.05	0.37	<0.05	<0.05	<0.05	4.82	0.45	0.14	<0.05	<0.05	0.78	<0.05	<0.05	<0.05	2.74	<0.05	<0.05	<0.05
Copper	mg/ℓ Cu	2	0.2	<0.5	0.11	<0.01	<0.01	0.05	0.08	0.07	0.08	0.06	0.04	0.03	0.09	0.04	0.05	0.05	0.04	0.05	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.02
Free CN	mg/ℓ CN				<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.002	0.017	0.088	<0.002	<0.02	<0.02	<0.002	0.074	0.099	0.125	0	0.004	<0.002	0.002
Total CN	mg/ℓ CN	≤1.5			<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
Ammonium	mg/ℓ NH4	NG	5	NG	0.68	0.47	0.35	0.97	1.06	0.31	0.06	0.09	0.37	0.47	0.12	2.12	0.26	0.21	0.76	0.26	0.11	0.08	0.08	0.12	0.44	0.7	0.1	0.36
Zinc	mg/ℓ Zn	5	1	20	1.05	<0.05	<0.05	<0.05	<0.05	0.08	0.05	0.05	<0.05	<0.05	<0.05	0.12	0.26	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	0.05	0.54	<0.05	0.06	<0.05

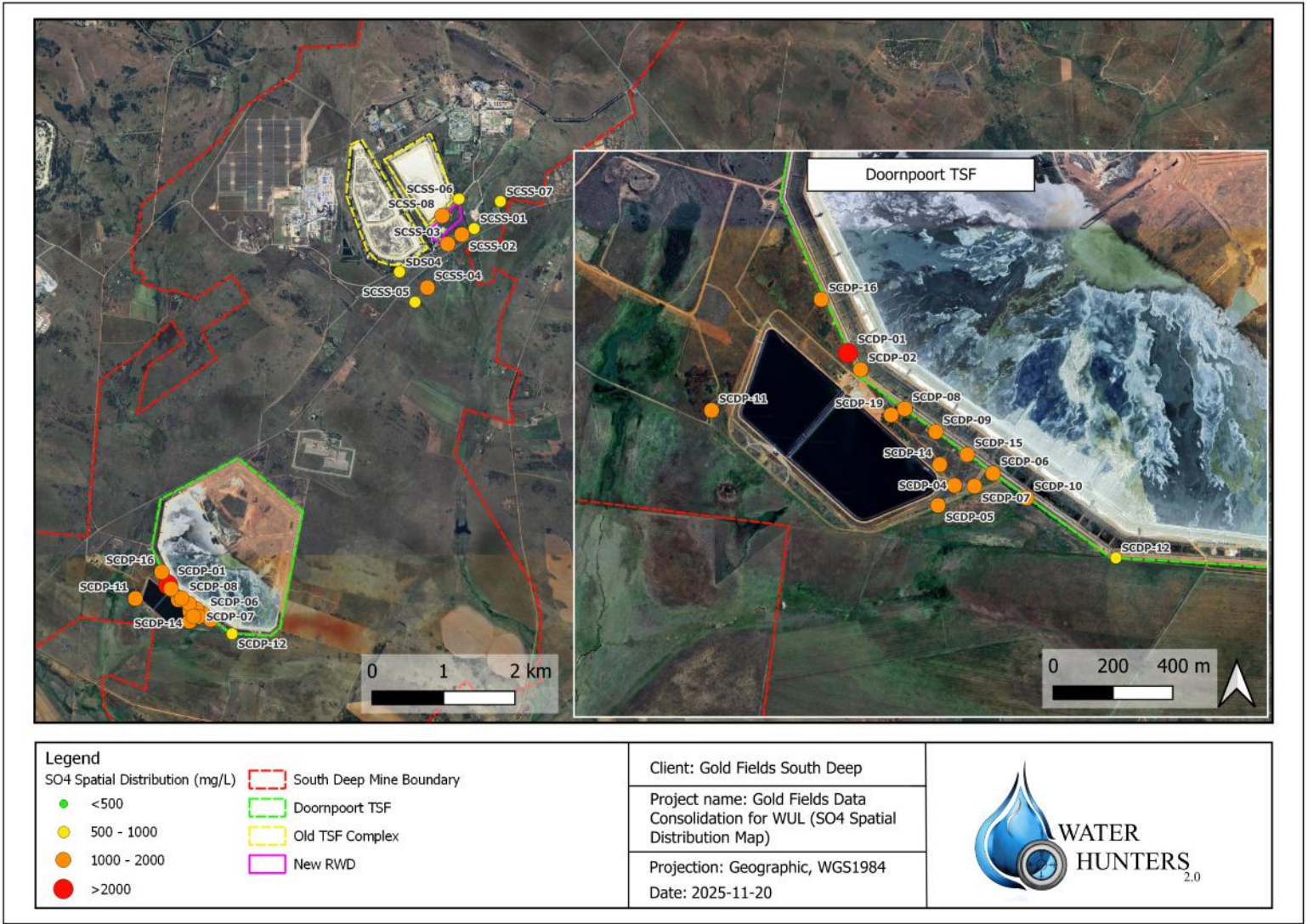


Figure 5.3 Map indicating the sulphate (SO4) distribution

6 AQUIFER CHARACTERISATION

6.1 Aquifer Vulnerability

Aquifer vulnerability assessment indicates the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. Stated in another way, it is a measure of the degree of insulation that the natural and manmade factors provide to keep contamination away from groundwater.

- Vulnerability is high if natural factors provide little protection to shield groundwater from contaminating activities at the land surface.
- Vulnerability is low if natural factors provide relatively good protection and if there is little likelihood that contaminating activities will result in groundwater degradation.

The DRASTIC method, proposed by Aller et al., (1985), is regarded as one of the best indices for groundwater vulnerability estimation. The DRASTIC index is obtained using the following equation:

$$\text{DRASTIC index} = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W$$

Appendix B outlines the ratings and weight factors of vulnerability used to calculate the DRASTIC index. The following definitions are provided for the factors influencing groundwater vulnerability:

- Depth to groundwater: Indicates the distance and time required for pollutants to move through the unsaturated zone to the aquifer.
- Recharge: The primary source of groundwater is precipitation, which aids the movement of a pollutant to the aquifer.
- Aquifer media: The rock matrices and fractures which serve as water bearing units.
- Soil media: The soil media (consisting of the upper portion of the vadose zone) affects the rate at which the pollutants migrate to groundwater.
- Topography: Indicates whether pollutants will run off or remain on the surface allowing for infiltration to groundwater to occur.
- Impact of the vadose zone: The part of the geological profile beneath the earth's surface and above the first principal water-bearing aquifer. The vadose zone can retard the progress of the contaminants.
- Hydraulic Conductivity: The permeability of the main aquifer unit

Based on the following assumptions and the criteria described in Appendix B (assuming a worst-case scenario):

- Depth to groundwater was calculated from the aquifer tests and is 3.32 mbgl
- Groundwater recharge is estimated to be around 3 % of MAP, which would equate to 20 mm/a.
- The aquifer media is classified quartzites and shale, with some andesite
- Soil media is classified as sand, clay and silt
- A gradient of 1 % was calculated for the underlying site.

- The vadose zone is classified as sand, clay and silt.
- Transmissivity of host geology is between 4 and 9 m²/day
- Dykes 0.1 m²/day
- Contact zones: 30 m²/day

Table 6-1 Aquifer Vulnerability Rating

Vulnerability	Rating
Highly vulnerable > 137	Natural factors provide little protection to shield groundwater from contaminating activities at the land surface.
Medium Vulnerability 93 to 136	Natural factors provide some protection to shield groundwater from contaminating activities at the land surface. However, based on the contaminant toxicity, mitigation measures will be required to prevent any surface contamination from reaching the groundwater table.
Low Vulnerability < 92	Natural factors provide relatively good protection and there is little likelihood that contaminating activities will result in ground water degradation.

The application of the DRASTIC method resulted in a vulnerability rating of 71, classifying the aquifer as having a low vulnerability.

6.2 Aquifer Classification

The aquifer(s) underlying the subject area were classified in accordance with *A South African Aquifer System Management Classification* (Parsons, 1995).

The aquifers are classified according to the following definitions:

- **Sole Aquifer System:** An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
- **Major Aquifer System:** Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (Electrical Conductivity of less than 150 mS/m).
- **Minor Aquifer System:** These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.
- **Non-Aquifer System:** These are formations with negligible permeability that are regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

Based on locality and geology it can be concluded that the aquifer system in the study area can be classified as a “minor aquifer system”.

In order to achieve the Aquifer System Management and Second Variable Classifications, as well as the Groundwater Quality Management Index, a points scoring system as presented in Table 6-2 and Table 6-3 was used.

Table 6-2 Ratings – Aquifer System Management and Second Variable Classifications

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	2
Major Aquifer System:	4	
Minor Aquifer System:	2	
Non-Aquifer System:	0	
Special Aquifer System:	0 – 6	
Second Variable Classification (Weathering/Fracturing)		
Class	Points	Study area
High:	3	2
Medium:	2	
Low:	1	

Table 6-3 Ratings - Groundwater Quality Management (GQM) Classification System

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	2
Major Aquifer System:	4	
Minor Aquifer System:	2	
Non-Aquifer System:	0	
Special Aquifer System:	0 – 6	
Aquifer Vulnerability Classification		
Class	Points	Study area
High:	3	2
Medium:	2	
Low:	1	

As part of the aquifer classification a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required. The GQM Index is obtained by multiplying the rating of the aquifer system management and the aquifer vulnerability. The GQM index for the study area is presented in Table 6-4.

The level of groundwater protection based on the Groundwater Quality Management Classification:

$$\begin{aligned}
 \text{GQM Index} &= \text{Aquifer System Management} \times \text{Aquifer Vulnerability} \\
 &= 2 \times 2 = 4
 \end{aligned}$$

Table 6-4 GQM Index for the Study Area

GQM Index	Level of Protection	Study Area
<1	Limited	4
1 – 3	Low Level	
3 – 6	Medium Level	
6 – 10	High Level	
>10	Strictly non-degradation	

There exists a moderate likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. In terms of the Groundwater Management Quality Index the aquifer has medium vulnerability and protection level is **medium**.

7 GROUNDWATER RESERVE DETERMINATION

A groundwater reserve determination (GRD) was conducted as part of the Water Use Licence Application (WULA) amendment. The GRD aims to establish a groundwater reserve (GW) to help quantify the likely impacts of the proposed groundwater abstraction. It is important to quantify groundwater volume and the potential impact of rainfall and abstraction on this volume. A groundwater balance helps determine the safe abstraction rate for the boreholes in use. The GRD was assessed using Aquiworx, which is a surface and groundwater monitoring application that features a GIS front end, and utilizes Microsoft Excel as a database.

The data used for the GRD calculation was derived from the field investigation, and the South African Groundwater Resource Assessment Ver. 2 (GRAII) datasets, and the National Integrated Water Information System (NIWIS) (DWS, 2025).

7.1 Catchment Area Delineation

The site falls within quaternary catchment C22J, covering an area of 670 km² (DWAF, 2011).

7.2 Calculation of Reserve

Effective groundwater recharge is the portion of rainfall that replenishes the aquifer, while the rest flows as surface water, evaporates, or is stored in the soil. Geology, soil properties, surface runoff, and stream characteristics all influence recharge rates. The estimated recharge for the area is detailed in Table 7-1.

Table 7-1 Estimated Recharge Calculation Summary

Description	Unit	C22J
Annual Total Rainfall	mm	697
Recharge	(mm/a)	46.01
Delineated Catchment Area	(km ²)	670.00
Delineated Project Area	(km ²)	74.4
Annual Recharge Volume	(m ³ /a)	30 821 005
Project Area Annual Recharge Volume	(m ³ /a)	3 422 512

7.2.1 Total Abstraction

Based on the findings of the sustainable yield assessment, and the proposed sustainable yields for the water supply boreholes. A summary of current use in the catchment and total proposed abstraction, based on the maximum sustainable yield (as calculated in section 5.2 of this report) is summarised in Table 7-2.

Table 7-2 Groundwater Abstraction Summary

Groundwater Requirement	
Use	C22J
	m ³ /a
Proposed Abstraction	3 686 544
WARMS Abstraction	2 379 256

7.3 Delineated Catchment Area Water Balance Calculation

The catchment area water balance is based on the information obtained from the National Integrated Water Information System and Aquiworx and is summarised in Table 7-3 below.

Table 7-3 Water Balance Summary

Description	Quaternary C22J	Unit
Recharge through Precipitation	30 821 005	(m ³ /a)
Proposed Abstraction	3 686 544	(m ³ /a)
Abstracted (WARMS)	2 379 256	(m ³ /a)
Surplus Amount	24 755 205	(m³/a)

Table 7-4 summarises the project water balance summary. For the project area the abstraction amount exceeds the recharge through precipitation amount, with reference to the catchment the abstraction is within recharge limits.

Table 7-4 Project Area Waterbalance Summary

Description	Project area	Unit
Recharge through Precipitation	3 422 512	(m ³ /a)
Proposed Abstraction	3 686 544	(m ³ /a)
Surplus Amount	264 032	(m³/a)

7.4 Scale of Abstraction

The Department of Water and Sanitation (DWS) categorises groundwater abstraction licence applications based on the amount of recharge that is used by the applicant in relation to the specified property. The category of abstraction is calculated as follows:

$$AREA_{PROP} * RE = RE_{AREA} \text{ (m}^3\text{/a)}$$

$$ABS_{EX} + ABS_{NEW} = ABS_{TOTAL} \text{ (m}^3\text{/a)}$$

$$ABS_{SCALE} = (ABS_{TOTAL} / RE_{AREA}) * 100$$

Where:

- Size of property (Area_{PROP})

- Recharge to Property (RE)
- Existing Use Volume (ABS_{EX})
- New Use Volume (ABS_{NEW})
- Scale of Abstraction (ABS_{SCALE})

Categories A, B, and C each have specific information requirements that applicants must provide to the DWS. The category of abstraction is summarised in

Table 7-5.

Table 7-5 Categories of Abstraction

Category	Description
A	Small-scale abstractions (<60% Recharge)
B	Medium-scale abstractions (60 - 100% Recharge)
C	Large-scale abstractions (>100% Recharge)

The proposed groundwater abstraction is 3 686 544 m³/a (10 100 m³/day) falls under the Department of Water and Sanitation (DWS) classification of " **Medium-scale abstractions (60 - 100% Recharge)**".

8 CONCEPTUAL SITE MODEL

Three distinct aquifers are present in the study area, comprising:

- (a) an upper, shallow weathered-material aquifer,
- (b) an intermediate competent and fractured-rock aquifer extending to depths of approximately 60–100 m below surface, and
- (c) a deep, confined aquifer.

Groundwater levels show a clear hydraulic separation between the shallow weathered aquifer and the underlying fractured-rock system. Water levels in the weathered zone range from surface to approximately 12 mbgl, whereas the fractured-rock aquifer exhibits deeper water levels of 15–35 mbgl. Regional groundwater flow broadly mimics topography, and there is no evidence of mine dewatering affecting the natural flow regime. Instead, regional flow is primarily controlled by two impermeable Gembokfontein dykes that transect the area. Enhanced transmissivity along the dyke–host rock contact zones forms preferential groundwater flow pathways.

Several surface infrastructure components act as potential sources of contamination to the underlying aquifer systems. Contaminants are expected to migrate along the prevailing groundwater gradients, moving from topographically elevated areas toward lower-lying discharge zones. Structural geological features, particularly the Gembokfontein dykes underlying both the Old TSF complex and the Doornpoort TSF, are likely to influence plume geometry by constraining or redirecting flow pathways.

Geochemical characterisation of leachates from operational and post-closure phases indicates that tailings seepage is likely to exhibit acid rock drainage characteristics, with elevated TDS (2,000–4,000 mg/L) and sulphate (800–2,800 mg/L), accompanied by elevated metals including Mn (3–24 mg/L), Ni (2–14 mg/L), Al (0–38 mg/L) and As (1–2 mg/L) (Cruywagen & Usher, 2008; Metago, 2008; 2009; Mintek, 2008). These concentrations represent the upper-bound contaminant load likely to migrate into the shallow and fractured aquifer systems beneath the TSF complexes.

The site model is summarised in the Table 8-1 below. Scavenger is deemed to provide effective hydraulic containment by reversing and flattening local gradients, intercepting seepage directly beneath and adjacent to the TSF, and preventing plume migration into transmissive pathways. This breaks the Source–Pathway–Receptor model by removing the hydraulic connection between the contamination source and downstream receptors, thereby eliminating exposure and ensuring controlled management of contaminated groundwater.

Hydraulic containment through scavenger wells contributes directly to Water Conservation and Water Demand Management by preventing seepage losses, capturing and reusing groundwater within the mine’s process water circuit, reducing external freshwater abstraction, and stabilising the operational water balance. This intervention therefore not only protects groundwater quality but also reduces overall water demand and enhances water-use efficiency across the facility.

Table 8-1 Summarised Conceptual Site Model (CSM)

Source	Primary Contaminants / Characteristics	Pathway	Receptor	Controls / Notes
Old TSF complex	Acidic seepage with elevated TDS, SO ₄ and metals	Infiltration through TSF base and sidewalls → percolation through unsaturated weathered zone → advective–dispersive transport in shallow weathered aquifer → downward leakage into fractured-rock aquifer	Shallow weathered aquifer; fractured-rock aquifer; down-gradient boreholes; discharge areas in lower-lying terrain and surface water features	Seepage migration follows groundwater gradients; plume geometry influenced by Gemsbokfontein dykes and contact zones
Doornpoort TSF	Acidic seepage with elevated TDS, SO ₄ and metals	Infiltration through TSF footprint → unsaturated weathered zone → shallow groundwater → preferential flow along fracture zones and dyke–host contacts	Shallow and fractured aquifers beneath and down-gradient of Doornpoort TSF; down-gradient abstraction/monitoring boreholes; possible baseflow to streams/wetlands	Structural controls (dykes) may impound or channel plume; contact zones provide high transmissivity pathways

9 GROUNDWATER FLOW MODEL DEVELOPMENT

A groundwater model is any computational method that represents an approximation of an underground water system. While groundwater models are, by definition, a simplification of a more complex reality, they have proven to be useful tools over several decades for addressing a range of groundwater problems and supporting the decision-making process.

In nature, groundwater flow patterns are complex, and continuously change with time. Some simplifications are thus required for the purposes of modelling. One important consideration in the description of flow processes relates to the temporal variability of the flow. A system is said to be in a steady state when the flow processes are (at least to a good approximation) constant with time. The inflows to and the outflows from the system are equal and, as a result, there is no change in storage within the aquifer. This also means that the hydraulic heads and water table elevation do not change significantly with time. When the inflows term and outflows term differ, the total amount of water in the system under consideration changes, the heads and water table elevation change and the system is in an unsteady, or transient, state.

9.1 Objectives of the Modelling

The purpose of modelling in this report is to assist Goldfields in groundwater management through the identification of approaches to dewatering and contaminant prevention.

9.2 Modelling Package

A finite difference numerical model was created using AquaVeo's Groundwater Modelling System (GMS) as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes.

MT3DMS is a 3-D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS uses a modular structure like the structure utilized by MODFLOW and is used in conjunction with MODFLOW in a two-step flow and transport simulation. Heads are computed by MODFLOW during the flow simulation and utilized by MT3DMS as the flow field for the transport portion of the simulation.

9.3 Assumptions and limitations

Simplifying assumptions regarding the direction of flow in aquifers and aquitards are often made to reduce the complexity for the purposes of mathematical analysis of the flow problem (both for steady state and unsteady state systems). One of these is that the flow in the aquifer is strictly horizontal, and that flow in aquitards is vertical. These assumptions are based on the observation that horizontal head gradients in aquifers are usually much greater than vertical gradients, and that the flow through aquitards tends to be along the shortest possible flow path.

Model predictions are uncertain because models are built on information constraints and because

the capacity to capture real-world complexity in a model is limited. In many cases results from models are presented in a way that suggests there is one right answer provided by the model, such as the presentation of a single set of head contours or hydrographs for a particular prediction. However, it is more useful (and correct) to show that all model predictions contain uncertainty and that, given the available data, there is a distribution or range of plausible outputs that should be considered for each model prediction.

9.4 Model setup

The model was initialised using the hydraulic conductivity values discussed in section 5.15.1.2 and subsequently calibrated against observed water levels. In accordance with literature values, the vertical hydraulic conductivities were for all layers consistently set at 10% of the horizontal hydraulic conductivities. This approach avoids the introduction of another unknown set of models respectively calibration parameter, by tying the vertical and horizontal hydraulic conductivities.

9.4.1 Model boundary

The model boundary has been chosen based topographic elevations no flow boundaries (north) and constant heads represented by the Leeuspruit in the west and an unnamed tributary of the Rietspruit in the east that confluence in the south.

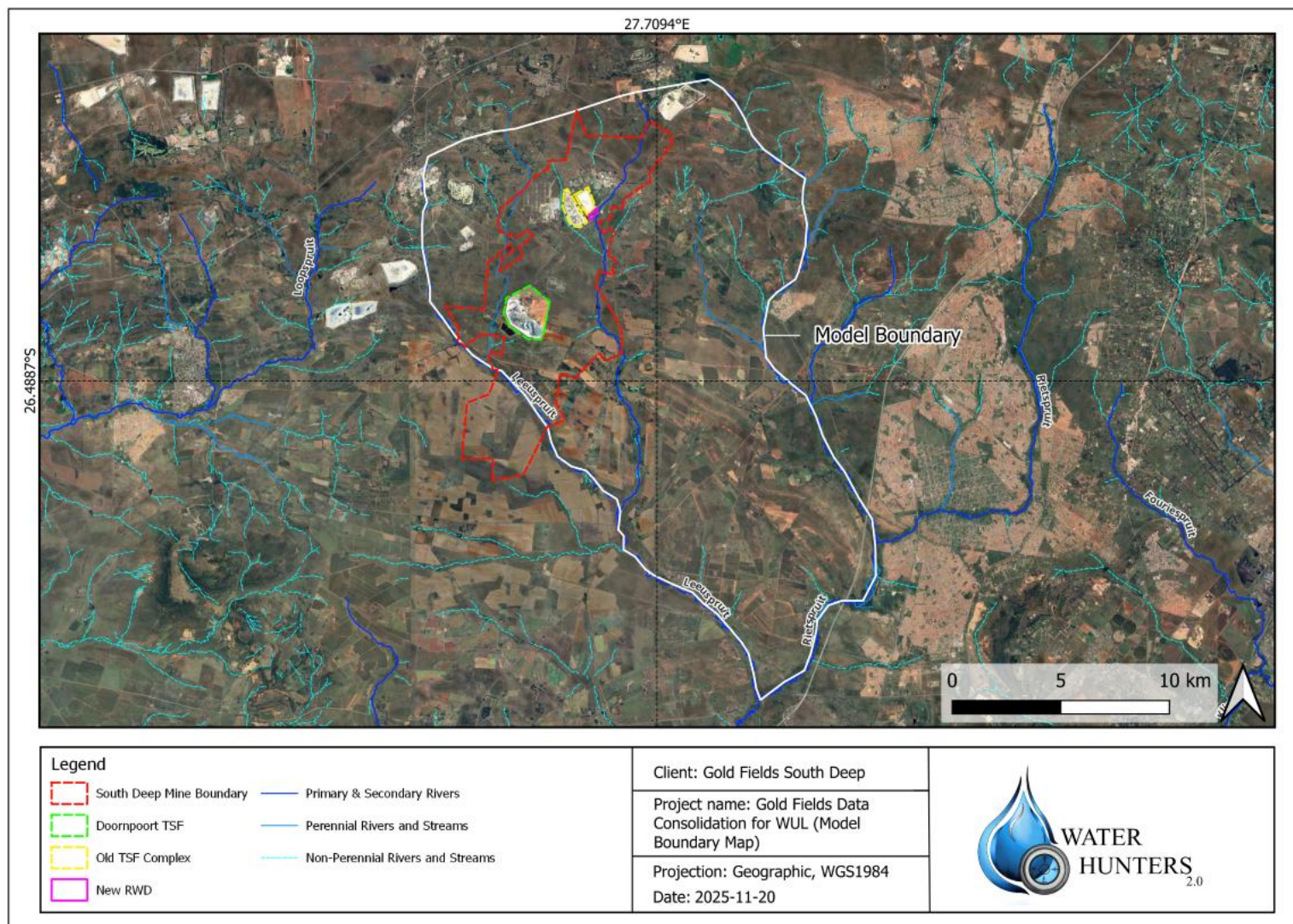


Figure 9.1 Model boundary

9.5 Construction of the Finite Difference Grid

The numerical model covers a total area of 22 918 m x 31 309 m. A finite difference network (grid) consisting of 765 x 596 x 3 was designed to provide a high resolution of the numerical solution, to accommodate model area. The grid was refined around the mining area to provide a higher resolution. The grid area is shown in Figure 9.2 below.

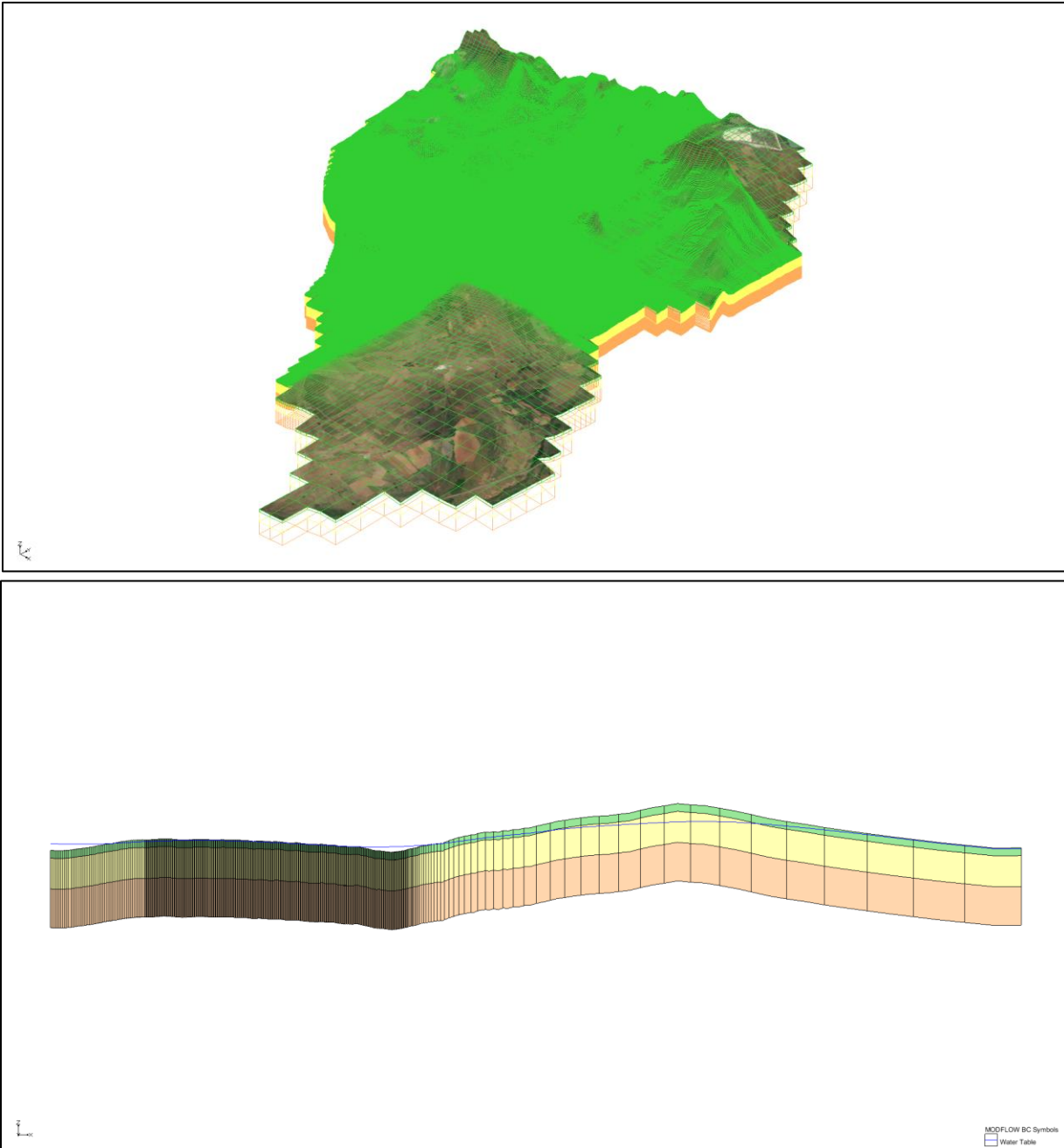


Figure 9.2 **Model grid area**

9.6 Model layers

A three-layer model was constructed with the details summarised in Table 9-1 below. Inputs are based on aquifer test data and information from published sources.

Table 9-1 Layers

Layer	Depth from (m)	Depth to (m)	Thickness (metres)	K values (m/d)
Upper regolith	0	5	5	0.1
Upper Weathered	5	30	25	0.085
Lower Fractured	30	100	70	0.0055
Structures	-	-	-	1

9.7 Recharge

A recharge percentage of 3%² was used over natural ground whereas recharge over tailings was assigned 20% of rainfall³. A recharge coefficient of 20% of MAP was applied to represent seepage beneath the TSF. This value aligns with DWAF Best Practice Guidelines G1 and G2 (2006), the MRD Code of Practice (DMR, 2013), international hydrogeotechnical literature (Aubertin et al., 2009; Ritcey, 2005) and is consistent with DWS-accepted values for unlined tailings facilities (typically 10–25% of MAP).

This climatic data and recharge values is detailed in Table 9-2 below.

Table 9-2 Recharge estimation

Climatic data & Recharge			
Annual		633	mm/a
Evaporation		1400	mm/a
Recharge to shallow aquifer	3%	19	mm/a
Recharge to TSF areas	20%	126.6	mm/a

9.8 Hydraulic Conductivity (k)

In the model the hydraulic conductivities derived from the Cooper–Jacob analysis were used as the primary calibration targets for horizontal K in the active scavenger wellfield domain. The field-based K values, ranging from 0.07 to 4 m/day (1×10^{-6} to 5×10^{-5} m/s), provide realistic bounds for assigning layer-specific K zones within the model.

The hydraulic conductivity of the model was calibrated together with recharge. The calibrated hydraulic conductivity (k) of layer 1 is 0.1 m/d, layer 2 is 0.09 m/d and layer 3 is 0.005 m/d.

² Xu, Y. and H.E. Beekman, 2019, Review: Groundwater recharge estimation in arid and semi-arid southern Africa. Hydrogeology Journal, volume 27, pages 929–943, doi: 10.1007/s10040-018-1898-8.

³ DWAF (Department of Water Affairs and Forestry). 2006. Best Practice Guideline G1: Stormwater Management for Mines in South Africa.

9.9 Steady State Simulation (Calibration)

Water level data obtained from monitoring was used to calibrate the steady state numerical groundwater flow model. The results obtained during the steady state scenarios were used as initial conditions to simulate dewatering. An average head error of less than 1.5 mbgl was obtained, which is deemed a good fit. The spread from the 1:1 line indicates moderate calibration error but without extreme outliers. The model performance appears acceptable for:

- Regional conceptual understanding
- Predictive simulations with moderate uncertainty

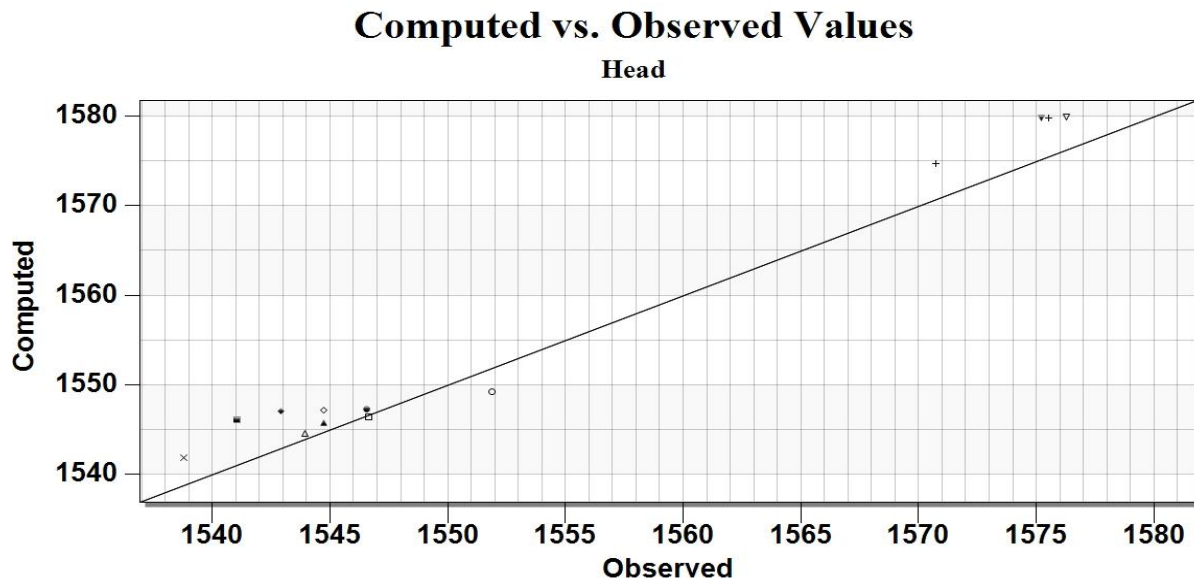


Figure 9.3 Steady state water level correlation

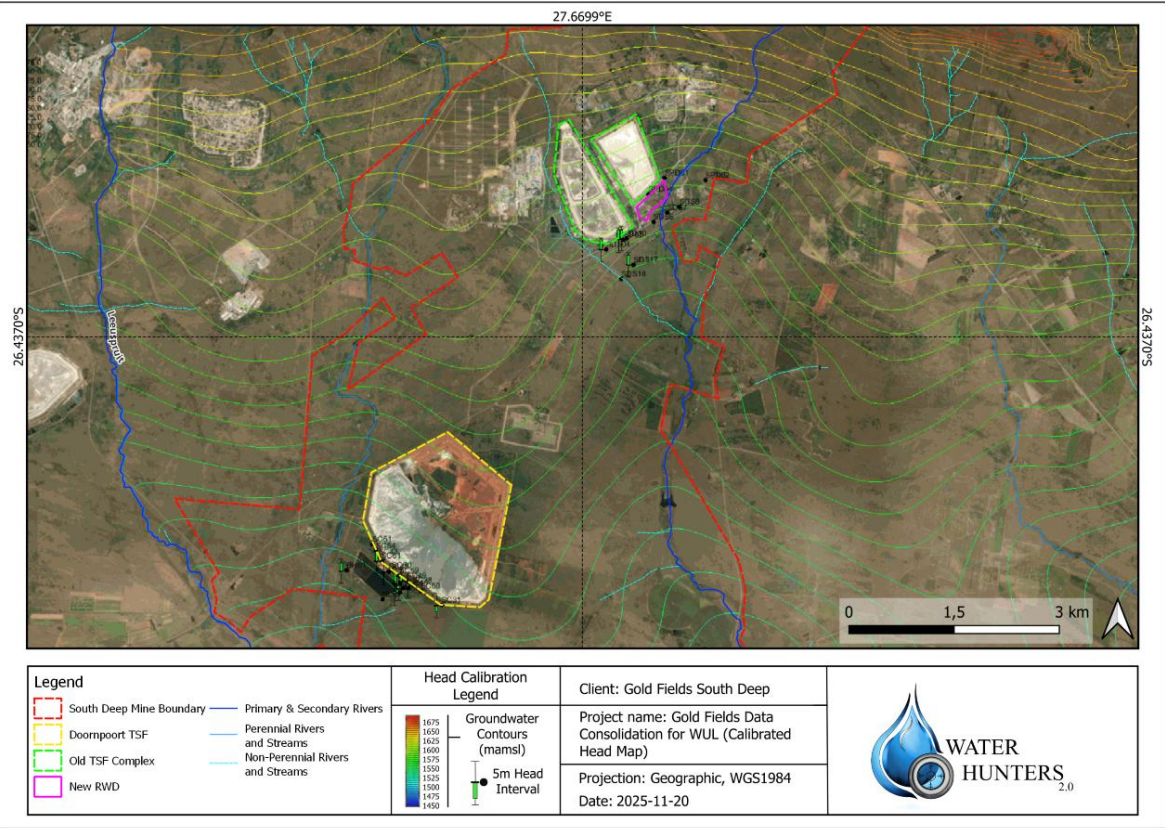


Figure 9.4 Calibrated head contours

9.10 Sensitivity analysis

In accordance with ASTM D5611 (Guide for Conducting a Sensitivity Analysis for a Groundwater Flow Model Application), a sensitivity analysis was undertaken to evaluate the robustness of the calibrated numerical model and to quantify how uncertainty input parameters affects predicted drawdowns and sulphate plume behaviour.

The analysis focuses on parameters that are both uncertain and influential in the context of the WUL amendment, namely hydraulic conductivity, recharge, vertical anisotropy, storage values, and contaminant transport parameters.

9.10.1 Parameters and Ranges Tested

The sensitivity analysis was conducted around the calibrated model described in section above which is based on field-derived hydraulic conductivity values (0.07–4 m/day, Cooper–Jacob analysis), a three-layer hydrostratigraphic model, and recharge values of 3% of MAP over natural ground and 20% of MAP over the TSFs.

The following parameter ranges were assessed:

Horizontal hydraulic conductivity (K_x , K_y)

Layer 1 (regolith), Layer 2 (weathered), Layer 3 (fractured) were each varied by $\pm 25\%$ and $\pm 50\%$ relative to the calibrated values.

Vertical anisotropy (K_z/K_x)

The base-case anisotropy ratio of 0.1 was varied to 0.05 and 0.2 to reflect plausible bounds for layered fractured systems.

Recharge

Natural recharge was varied between 2–5% of MAP.

TSF recharge was varied between 10–25% of MAP to reflect the range reported in national best-practice guidelines for unlined tailings facilities.

Storage (S_y)

Specific yield were varied by $\pm 50\%$ around their base values in transient simulations (where applicable).

Boundary condition placement

Constant-head river boundaries were shifted outward and inward by one to two model cells to test the influence of domain size and boundary location on drawdown and plume migration.

Transport parameters

Longitudinal dispersivity (α_L) was varied between 5–25 m.

Transverse dispersivity (α_T) was varied between $0.1 \cdot \alpha_L$ and $0.3 \cdot \alpha_L$.

Effective porosity (n_e) was varied between 0.05–0.2.

Sulphate source concentrations beneath the TSFs were varied by $\pm 25\%$ relative to the base-case loading.

Each sensitivity run altered one parameter group at a time (one-factor-at-a-time approach) while maintaining all other inputs identical to the calibrated model. A small number of combined “worst-case” runs (low K, high recharge, high source loading) were also simulated to bracket the upper bound of potential impact.

9.10.2 Model sensitivity

The sensitivity analysis indicates that:

- Horizontal hydraulic conductivity in the weathered and fractured layers exerts the greatest influence on simulated drawdowns beneath the TSFs and on the spatial extent of the cones of depression. Reducing K by 50% results in a noticeable increase in drawdown immediately around the scavenger wells but does not cause the drawdown cone to extend beyond the mining right boundary. Conversely, increasing K by 50% slightly broadens the drawdown footprint but reduces maximum drawdown at individual wells due to increased transmissivity.
- Vertical anisotropy (K_z/K_x) has a secondary influence, mainly affecting vertical gradients and the distribution of drawdown between layers. Variations within the tested range do not materially change drawdown at surface receptors or the predicted reduction in baseflow.
- Recharge is moderately influential at a regional scale, but changes within the tested range (2–5% MAP natural, 10–25% MAP TSF) do not alter the conclusion that the scavenger wells effectively dewater the shallow aquifer beneath the TSFs and maintain a hydraulic barrier towards the Leeuspruit and unnamed tributary.
- Boundary location changes (domain expansion/contraction) show minimal impact on the local dewatering pattern around the TSFs, confirming that the chosen model domain is adequate for the purposes of assessing site-scale impacts.
- The sensitivity analysis indicates that:
 - Horizontal hydraulic conductivity in the weathered and fractured layers exerts the greatest influence on simulated drawdowns beneath the TSFs and on the spatial extent of the cones of depression. Reducing K by 50% results in a noticeable increase in drawdown immediately around the scavenger wells but does not cause the drawdown cone to extend beyond the mining right boundary. Conversely, increasing K by 50% slightly broadens the drawdown footprint but reduces maximum drawdown at individual wells due to increased transmissivity.

- Vertical anisotropy (K_z/K_x) has a secondary influence, mainly affecting vertical gradients and the distribution of drawdown between layers. Variations within the tested range do not materially change drawdown at surface receptors or the predicted reduction in baseflow.
- Recharge is moderately influential at a regional scale, but changes within the tested range (2–5% MAP natural, 10–25% MAP TSF) do not alter the conclusion that the scavenger wells effectively dewater the shallow aquifer beneath the TSFs and maintain a hydraulic barrier towards the Leeuspruit and unnamed tributary.
- Boundary location changes (domain expansion/contraction) show minimal impact on the local dewatering pattern around the TSFs, confirming that the chosen model domain is adequate for the purposes of assessing site-scale impacts.

9.11 Numerical Modelling Scenarios

The following numerical scenarios were simulated from the calibrated model:

- Scenario 1: Abstraction from scavenger wells (Dewatering impact)
- Scenario 2: Abstraction from future/conceptual scavenger wells (Dewatering impact)
- Scenario 3: Contaminant plume without scavenger wells (no mitigation)
- Scenario 4: Contaminant plume with scavenger wells (with mitigation)

9.11.1 Scenario 1 - Abstraction from existing scavenger wells (Dewatering impact)

Abstraction from the scavenger wells:

- South deep scavenger wells - 2 513 m³/day to 3000 m³/day and
- Doornpoort tailings scavenger wells - 3 344 m³/day to 4000 m³/day
- Total 5 857 m³/day (min) to 7000 m³/day (max)

The model indicates the predicted cones of depression, resulting from the scavenger wells. The scavenger wells are effectively dewatering the shallow aquifer below the tailing's facilities creating a hydraulic barrier.

The unnamed tributary below the tailings in the north could experience baseflow reduction of between 2 to 3 m³/day and is deemed negligible.

9.11.2 Scenario 2 - Abstraction from future/conceptual scavenger wells (Dewatering impact)

Abstraction from the scavenger wells:

- South deep scavenger wells - 2 513 m³/day to 3000 m³/day and
- Doornpoort tailings scavenger wells - 3 344 m³/day to 4 000 m³/day
- Future scavenger well abstraction at 3 100 m³/day
- Total abstraction from all boreholes at 10 100 m³/day

The model indicates the predicted cones of depression, resulting from the scavenger wells. The

scavenger wells are effectively dewatering the shallow aquifer below the tailing's facilities creating a hydraulic barrier.

The unnamed tributary below the tailings in the north could experience baseflow reduction of between 3 to 4 m³/day and is deemed negligible.

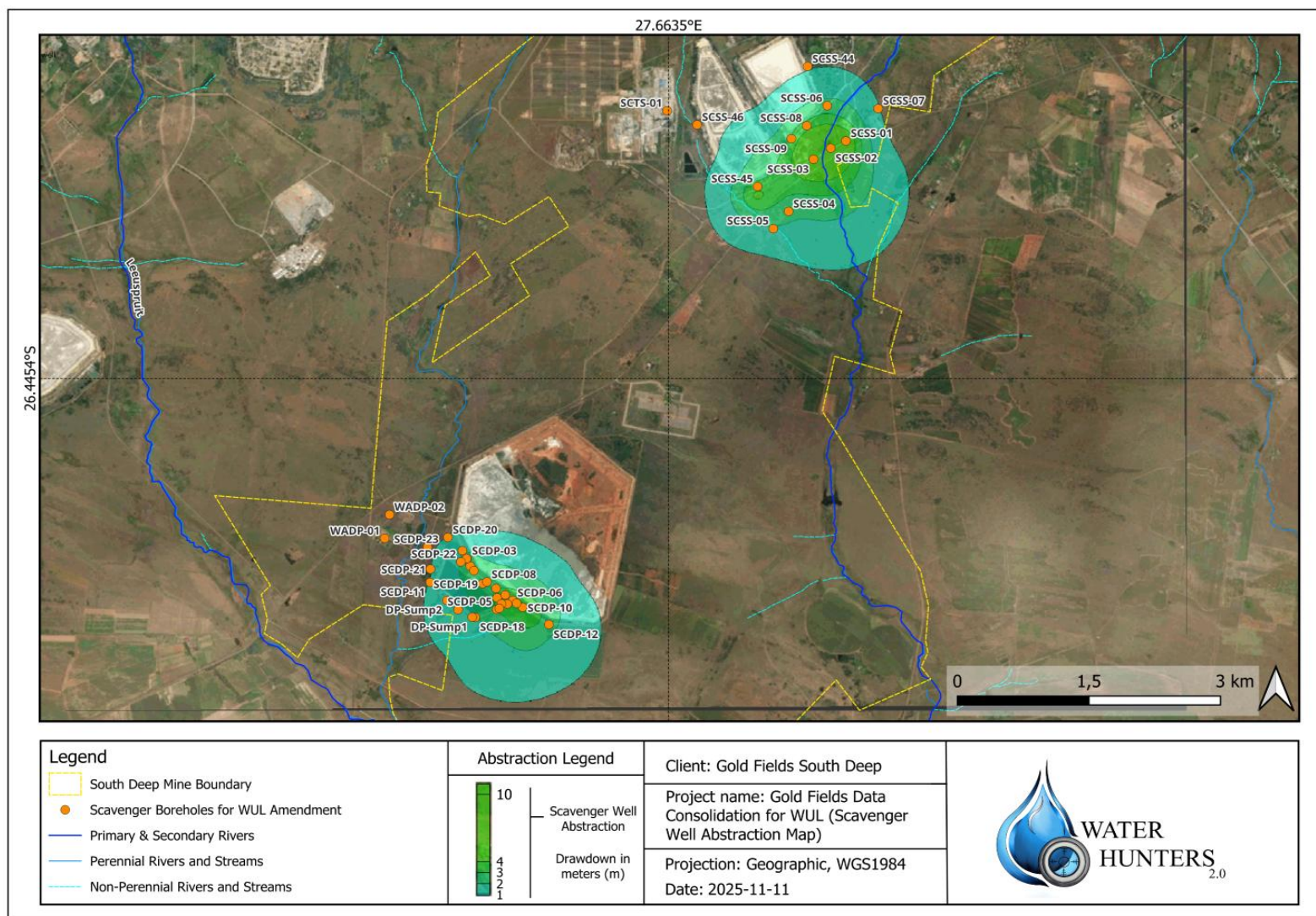


Figure 9.5 Dewatering scenario (Existing scavenger wells)

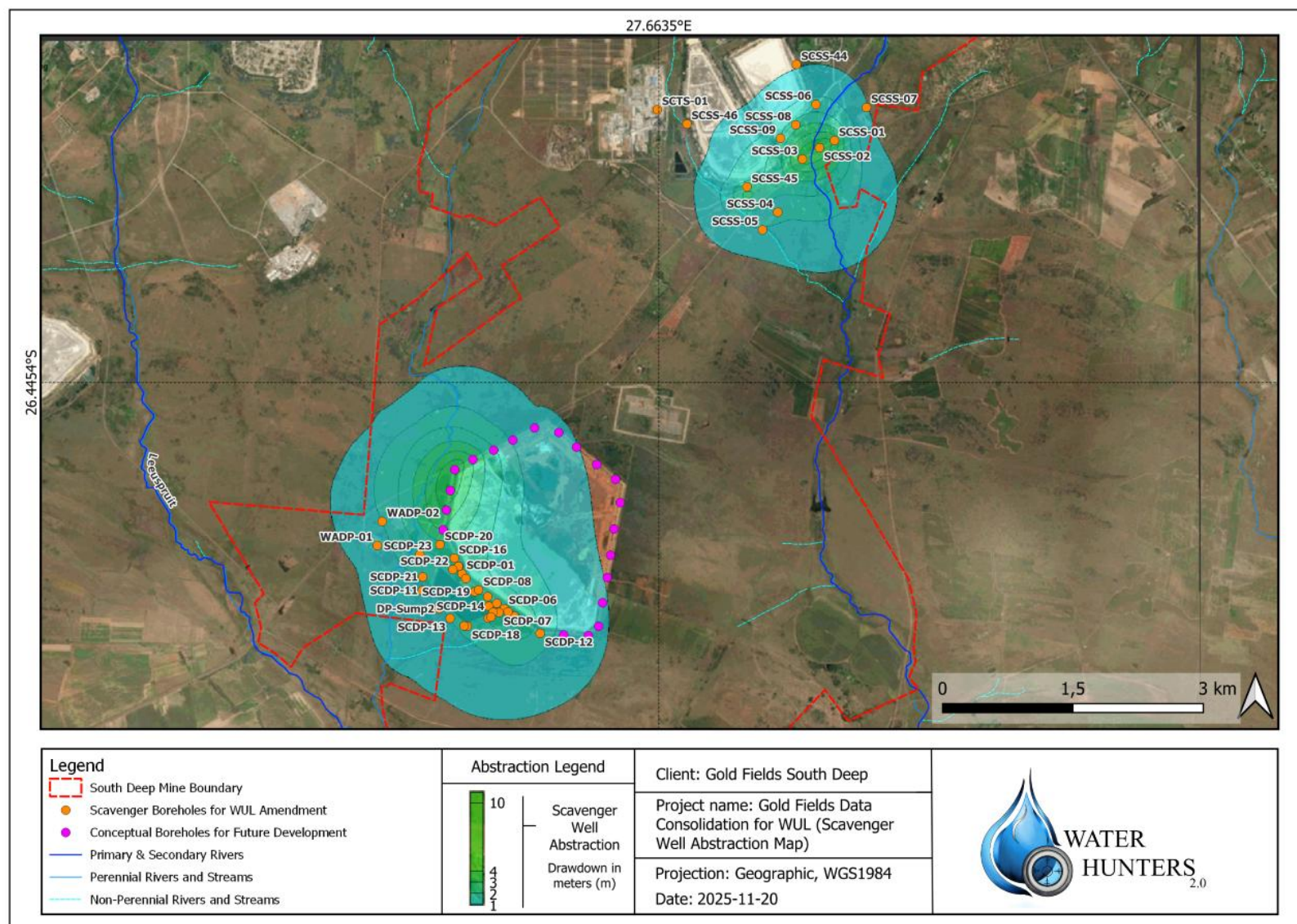


Figure 9.6 Dewatering scenario (Existing + Future scavenger wells)

9.11.3 Scenario 3 - Contaminant plume without scavenger wells

This scenario simulated unmitigated plume movement of seepages from tailings likely to be acid rock drainage, high in total dissolved solids (2 000 - 4 000 mg/L), sulphate (800 - 2 800 mg/L), with sulphate use as conservative tracer. The plume expands at a rate of 20 to 30 m a year and dilutes at the plume front due to dilution with uncontaminated groundwater.

The average sulphate concentration entering the Leeuspruit is also expected to increase over time from approximately 500 mg/l during 2025 to 2800 mg/l in year 2050.

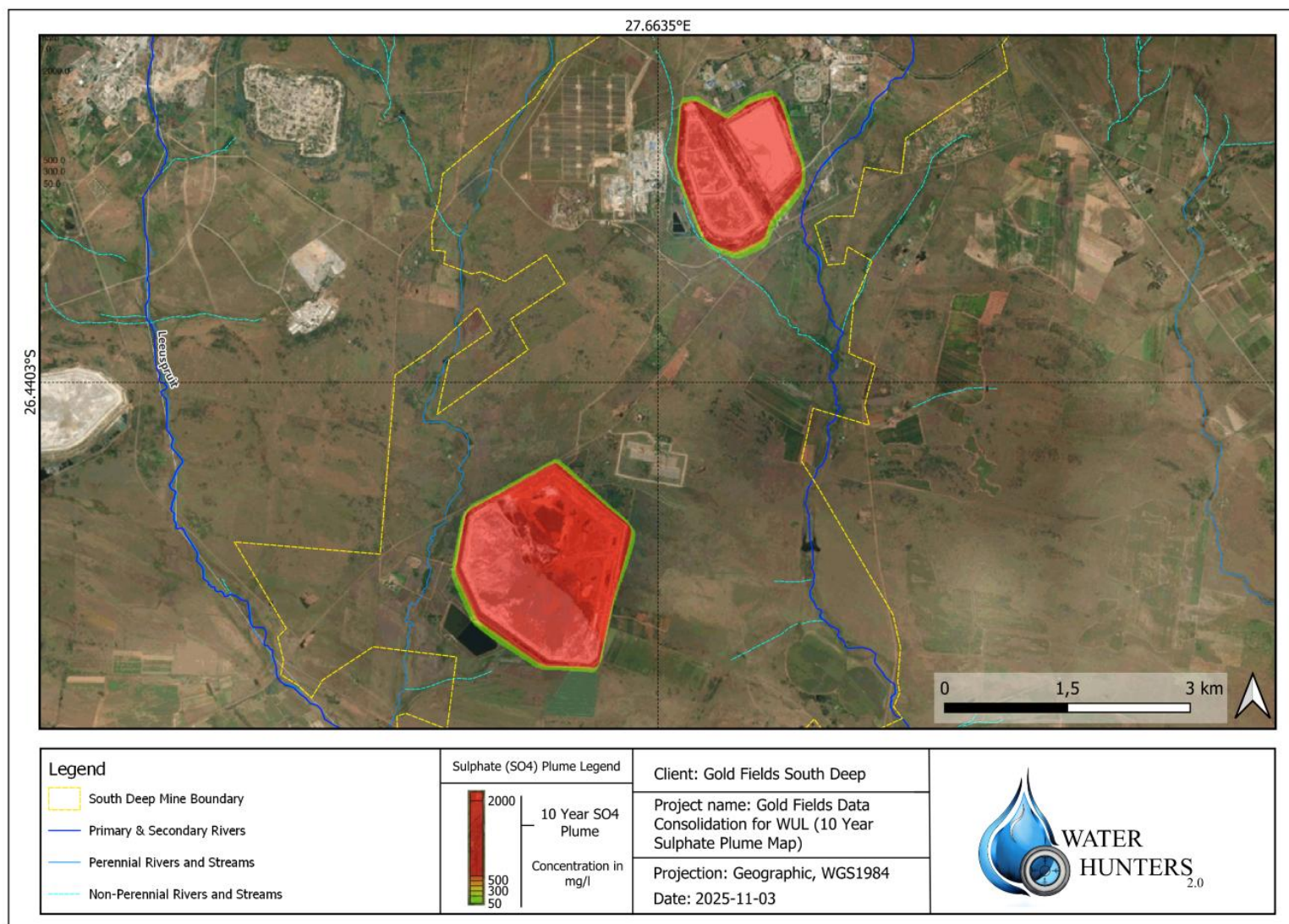


Figure 9.7 Unmitigated plume – 10 years

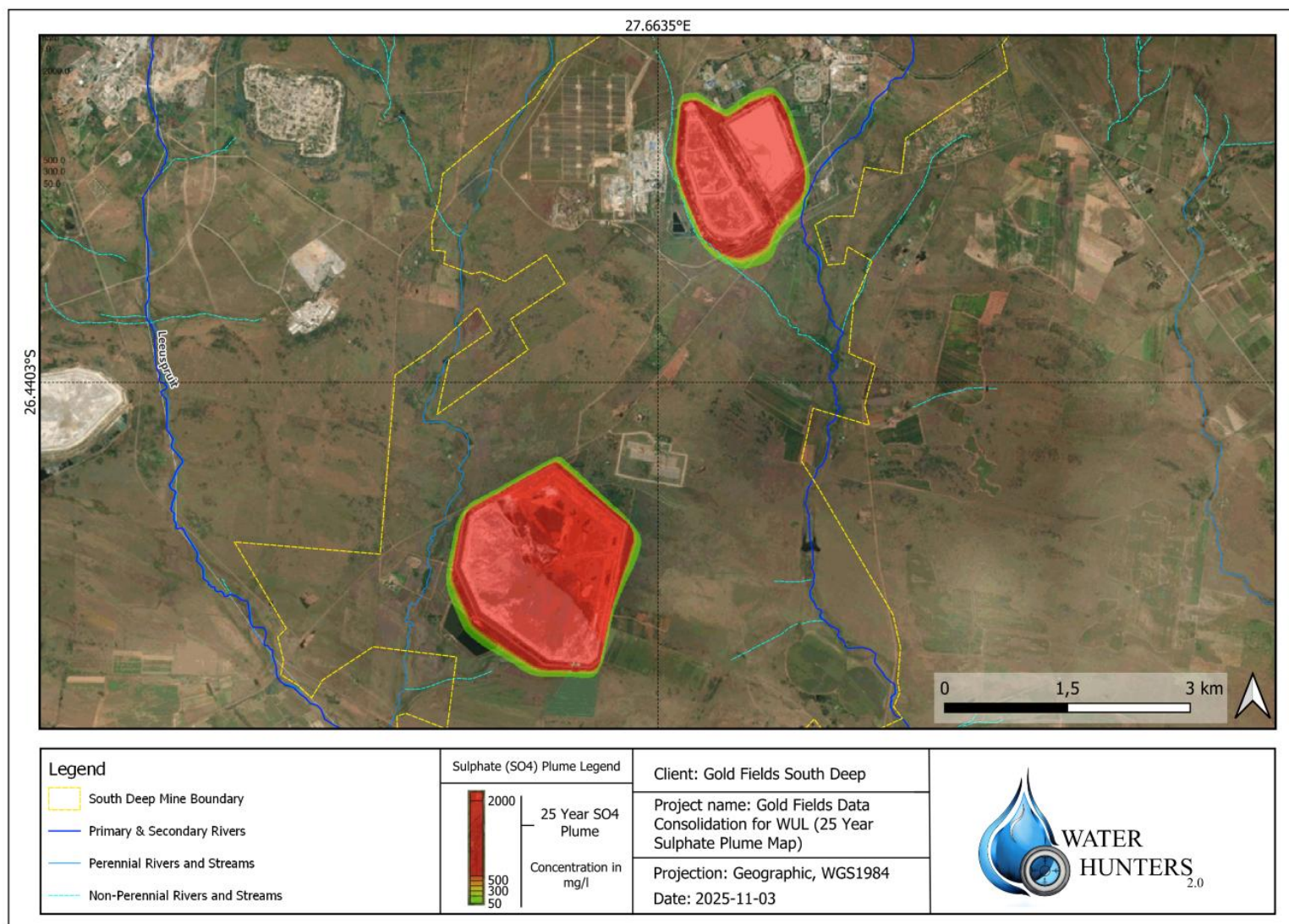


Figure 9.8 Unmitigated plume – 25 years

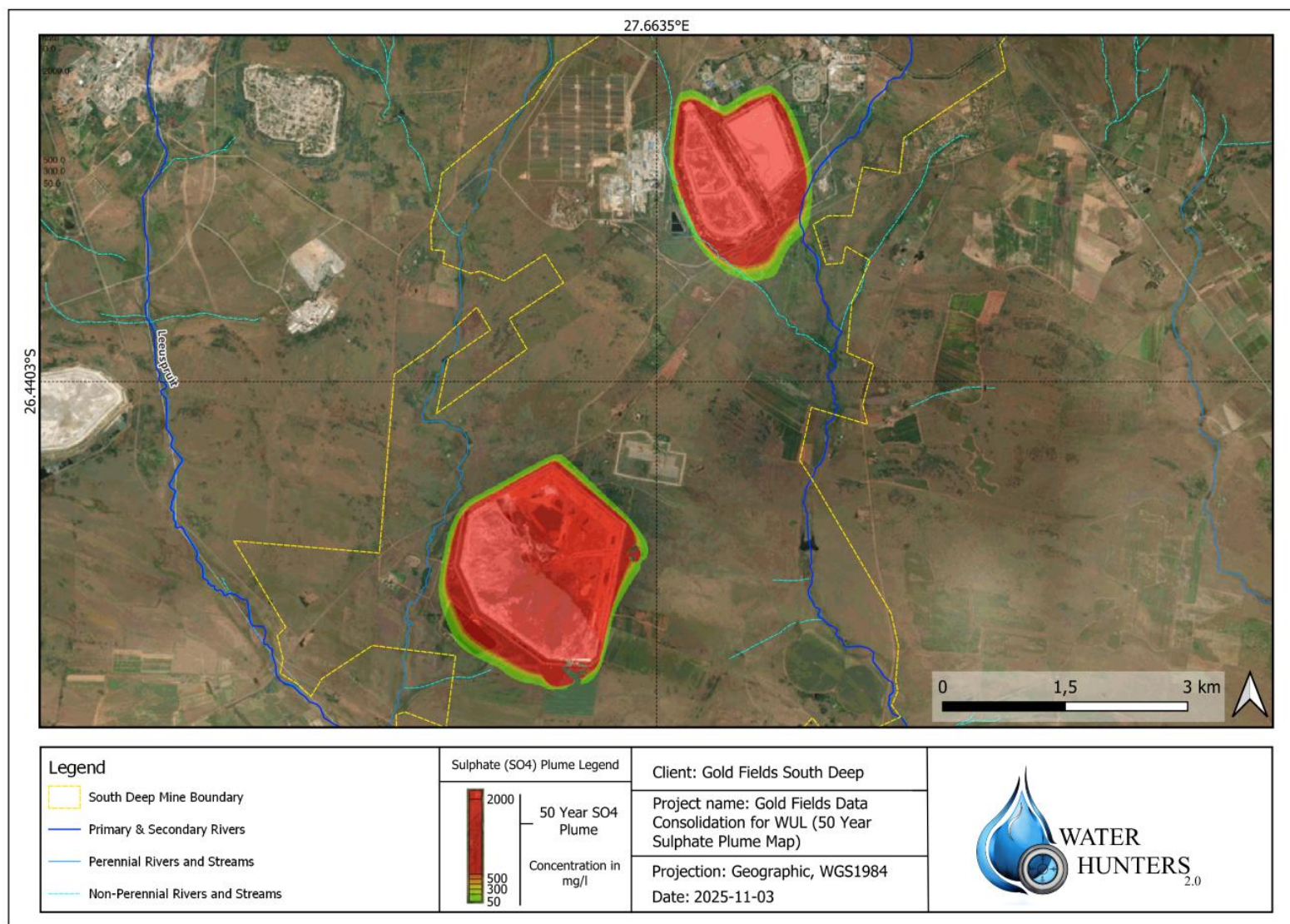


Figure 9.9 Unmitigated plume – 50 years

9.11.4 Scenario 4 - Contaminant plume with scavenger wells

This scenario simulated the plume with drilled scavenger wells as mitigation through hydraulic containment. It follows that there is a significant reduction in plume expansion with more than 40% of the plume captured as can be seen Figure 9.10 to Figure 9.11 below.

The average sulphate concentration entering the Leeuspruit is expected to decrease from approximately 2800 to 500mg/l in 2050. This confirms monitoring results in which scavenger wells are effective in abstracting contaminated groundwater from the aquifers, while the numerical groundwater flow and contaminant transport model show that the scavenger wells will be effective in containing the spread of the plume.

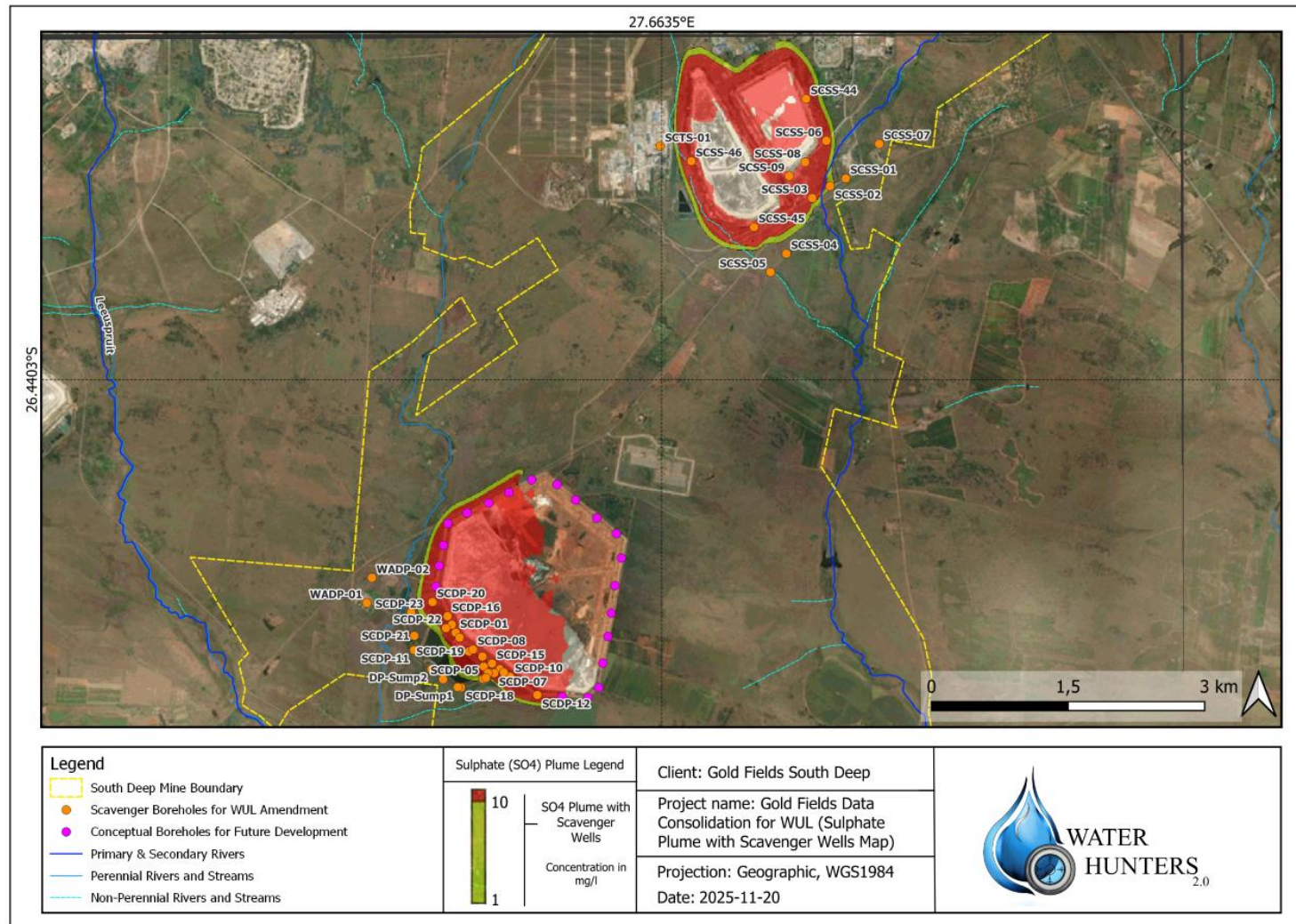


Figure 9.10 Mitigated plumes after 10 years with scavenger wells

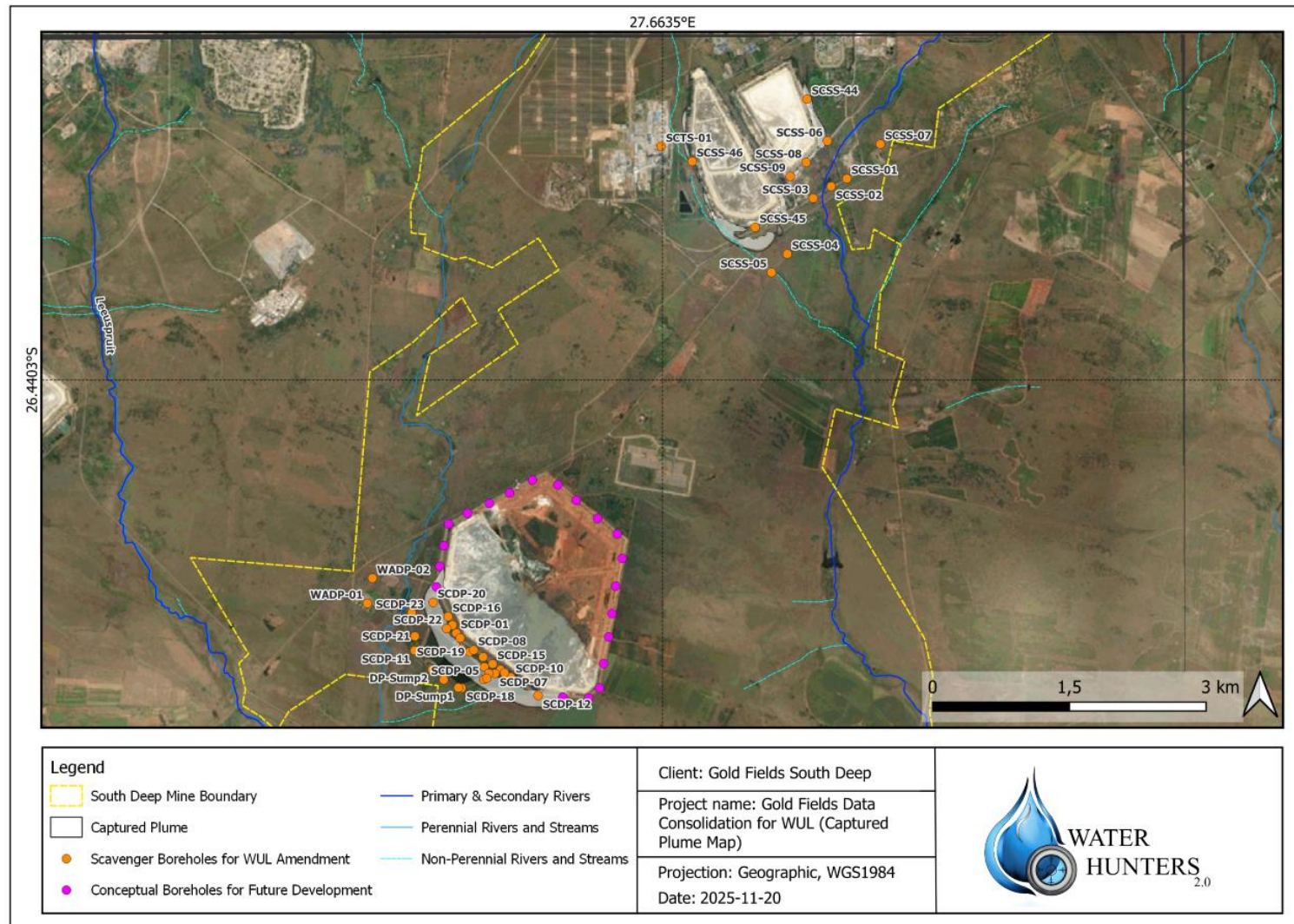


Figure 9.11 Mitigated plumes after 10 years with scavenger wells

9.12 Uncertainty and Error analysis

This section presents an uncertainty and error analysis for the South Deep–Doornpoort groundwater flow and transport model in line with ASTM D6170 (Standard Guide for Applying Error Analysis to Ground-Water Modelling) and supporting guidance in ASTM D5447 and ASTM D5981.

9.12.1 Hydrostratigraphy and connectivity

The system is represented by a three-layer structure (regolith, weathered zone and fractured bedrock), with confined dolomitic karst at depth. While the layering is consistent with regional geology, uncertainty remains regarding the degree of hydraulic connectivity between the shallow weathered aquifer and deeper fractured zones, especially around structural features such as dykes and contacts.

9.12.2 Flow system representation

Groundwater flow is represented as primarily horizontal in aquifers and vertical through aquitards, in line with standard practice. This introduces conceptual simplification, particularly near steep gradients or strong vertical leakage zones.

9.12.3 Source and sink conceptualisation

TSF seepage is represented as enhanced recharge (20% of MAP) over the TSF footprint, while abstraction is limited to the scavenger well network and mine dewatering. Some uncertainty exists around the spatial distribution and temporal variability of seepage rates within the TSFs.

9.12.4 Data Error and Measurement Uncertainty

Pumping test and step-test data have associated measurement errors in discharge, water level, and test duration. These translate into uncertainty in estimated transmissivity and hydraulic conductivity values (0.07–4 m/day) used to parameterise the model.

9.12.5 Water level and baseflow data

Monitoring water levels and streamflow/baseflow estimates include measurement noise, especially under short-term climatic variability.

9.12.6 Water quality data

Analytical uncertainty and sampling representativeness affect the sulphate concentration dataset used to define source terms and to interpret plume behaviour.

9.12.7 Parameter Error

Hydraulic conductivity is spatially heterogeneous; the model represents this heterogeneity using a limited number of zones informed by aquifer tests. Interpolating and grouping K values introduces parameter uncertainty.

Storage parameters are inferred from literature and/or short-term tests and therefore carry

significant uncertainty, particularly for deeper fractured units.

9.12.8 Recharge

Recharge is estimated as 3% of MAP over natural ground and 20% of MAP over TSFs, within ranges supported by literature and guidelines, but still uncertain at site scale.

Dispersivity, effective porosity and source concentration distributions are not uniquely constrained by monitoring data and therefore introduce uncertainty into plume extent and concentration predictions.

9.12.9 Boundary Condition and Domain Error

The model domain boundaries are placed along topographic divides and watercourses (no-flow and constant head boundaries). Misrepresentation of these boundaries (too close or too far) could influence regional gradients and heads, although sensitivity testing shows limited impact on local results around the TSFs.

Rivers are represented as constant-head features; in reality, river–aquifer interactions may be more dynamic.

9.12.10 Numerical Error

Use of a refined grid around the TSFs and convergence criteria within accepted tolerance limits means these errors are expected to be small compared to conceptual and parameter uncertainties.

9.12.10.1 Model Reliability

Considering the identified sources of uncertainty, the sensitivity test results, and the consistency between model predictions and observed system behaviour, the following conclusions are drawn:

- The model incorporates appropriate levels of simplification for a site-scale WUL assessment and is based on a robust dataset of aquifer tests, groundwater levels and chemistry.
- The most significant uncertainties relate to hydraulic conductivity distribution, recharge, and transport parameters, yet the sensitivity analysis demonstrates that these uncertainties do not alter the fundamental conclusions that:
 - Scavenger wells effectively dewater the shallow aquifer beneath the TSFs and create a hydraulic barrier.
 - Impacts on baseflow to the Leeuspruit and unnamed tributary are negligible; and
 - Operation of the scavenger wells materially reduces the sulphate plume footprint and downstream sulphate loads compared to the unmitigated scenario.
- The model is therefore considered fit for purposes as a decision-support tool for the WUL amendment, provided that:
 - Ongoing groundwater level and quality monitoring is maintained.
 - The model is updated and re-calibrated as new data become available

- (recommended at least every two years, as already proposed); and
- Any future changes in TSF operation, abstraction rates or site infrastructure are reflected in updated conceptual and numerical models.

10 IMPACTS ON SENSITIVE RECEPTORS

Based on available data the sensitive receptors in terms of groundwater applicable to the South deep and Doornkloof operations are the following:

- Aquatic biodiversity of the Leeuspruit
- Privately used boreholes for potable, livestock, and irrigation usage

Potential impacts such as loss of flow to these aquatic systems due to dewatering, and potential contaminant contributions, are discussed below.

10.1 Dewatering impacts on aquatic systems

Underground fissure water and scavenger well abstraction poses no tangible impact on either the Leeuspruit system. This is evident from long term water level monitoring data, and from current and previous modelling studies indicating no loss of the baseflow component.

- Dewatering from the underground does not extend to surface, with deeper aquifer dewatering limited to fissure water that does not extend to the baseflow component of the regolith (unsaturated) and weathered aquifer.
- Scavenger well abstraction cones of depression are limited to within 100 m of the positions of these wells, and do not extend to beyond the mining rights (

10.2 Dewatering impacts on privately used boreholes

As in the case of aquatic systems, dewatering and scavenger wells has no tangible impact on privately used boreholes. This is evident from long-term water level monitoring data, and from current and previous modelling studies.

- Dewatering from the underground does not extend to surface, with deeper aquifer dewatering limited to fissure water that does not extend to the baseflow component of the regolith (unsaturated) and weathered aquifer.
- Scavenger well abstraction cones of depression are limited to within 100 m of the positions of these wells, and do not extend to beyond the mining rights

10.3 Impact assessment of various activities

10.3.1 Impact Assessment Methodology

The EIA Regulations (2014, as amended) prescribe requirements to be adhered to, and objectives to be reached, when undertaking Impact Assessments. These are noted in the following sections contained within the EIA Regulations.

In terms of these Regulations, a description and assessment of the significance of any environmental impact should be considered when undertaking an impact assessment. This includes the following:

- Cumulative impacts that may occur because of the undertaking of the activity during the project life cycle;
- Nature of the impact;
- Extent and duration of the impact;

- The probability of the impact occurring;
- The degree to which the impact can be reversed;
- The degree to which the impact may cause irreplaceable loss of resources; and
- The degree to which the impact can be mitigated.

The overall significance of an impact / effect is ascertained by attributing numerical ratings to each identified impact (see **Table 10-3 Groundwater impact** quantification). The numerical scores obtained for each identified impact are multiplied by the probability of the impact occurring before and after mitigation. High values suggest that a predicted impact / effect are more significant, whilst low values suggest that a predicted impact / effect are less significant.

Table 10-1 Impact assessment criteria

Status of Impact	
+: Positive (A benefit to the receiving environment)	
N: Neutral (No cost or benefit to the receiving environment)	
-: Negative (A cost to the receiving environment)	
Magnitude:=M	Duration:=D
10: Very high/don't know	5: Permanent
8: High	4: Long-term (ceases with the operational life)
6: Moderate	3: Medium-term (5-15 years)
4: Low	2: Short-term (0-5 years)
2: Minor	1: Immediate
0: Not applicable/none/negligible	0: Not applicable/none/negligible
Scale:=S	Probability:=P
5: International	5: Definite/don't know
4: National	4: Highly probable
3: Regional	3: Medium probability
2: Local	2: Low probability
1: Site only	1: Improbable
0: Not applicable/none/negligible	0: Not applicable/none/negligible

To this assessment, the impact significance for each identified impact was evaluated according to the following key criteria outlined in the sub-sections below. The maximum value that can be achieved is 100 Significance Points (SP).

Significance = (Magnitude + Duration + Scale) X Probability

Table 10-2 Significance

Significance	Environmental Significance Points	Colour Code
High (positive)	>60	H
Medium (positive)	30 to 60	M
Low (positive)	<30	L
Neutral	0	N
Low (negative)	>-30	L
Medium (negative)	-30 to -60	M
High (negative)	<-60	H

Table 10-3 Groundwater impact quantification

Impact aspect	Magnitude	Duration	Scale	Probability	Without mitigation
Dewatering impacts on aquatic systems	2	4	1	-2	-14
Dewatering impacts on privately used boreholes	2	4	1	-2	-14
Contaminant impacts on aquatic systems	2	4	1	-2	-14
Contaminant impacts on privately owned boreholes	2	4	1	-2	-14
Cumulative impacts	2	4	1	-2	-14
Impact aspect	Magnitude	Duration	Scale	Probability	With mitigation
Dewatering impacts on aquatic systems	2	4	1	-2	-14
Dewatering impacts on privately used boreholes	2	4	1	-2	-14
Contaminant impacts on aquatic systems	2	4	1	-1	-7
Contaminant impacts on privately owned boreholes	2	4	1	-1	-7
Cumulative impacts	2	4	1	-2	-11

11 CONCLUSIONS

Water Hunters was appointed by Gold Fields to conduct a groundwater assessment and numerical model update on the existing scavenger boreholes and newly drilled scavenger boreholes at South Deep Gold Mine and Doornpoort TSF. The main purpose of the report is to assist Gold Fields with the amendment of existing Water Use License (WUL).

Current Groundwater Conditions

From the obtained information, it is concluded that there are at least two aquifers in the study area. These are a weathered aquifer, formed within the uppermost 15 metres of the subsurface, and a fractured aquifer associated with the secondary porosity formed from faults, fractures and the contact zones of fresh bedrock and the weathered zone.

Aquifer testing was conducted on 28 existing boreholes (25 existing scavenger boreholes and 3 existing monitoring boreholes) and 4 newly drilled boreholes.

Groundwater quality from the tested scavenger boreholes is poor with elevated Sulphate (SO₄) and TDS concentration values across the study area. The high SO₄ concentrations render the water, if untreated, unfit for human consumption.

Proposed abstraction

The proposed groundwater abstraction is 3 686 544 m³/a (10 100 m³/day) and falls under the Department of Water and Sanitation (DWS) classification of " Medium-scale abstractions (60 - 100% Recharge)".

Numerical Flow and Transport Model

The following numerical scenarios were simulated from the calibrated groundwater model:

- Scenario 1: Abstraction from scavenger wells (Dewatering impact)
- Scenario 2: Abstraction from future/conceptual scavenger wells (Dewatering impact)
- Scenario 3: Contaminant plume without scavenger wells (no mitigation)
- Scenario 4: Contaminant plume with scavenger wells (with mitigation)

Scenario 1 – Abstraction from scavenger wells (Dewatering impact)

Abstraction from the scavenger wells:

- South deep scavenger wells - 2 513 m³/day to 3000 m³/day and;
- Doornpoort tailings scavenger wells - 3 344 m³/day to 4 000 m³/day.
- Total 5 857 m³/day (min) to 7 000 m³/day (max).

The model indicates the predicted cones of depression, resulting from the scavenger wells. The scavenger wells are effectively dewatering the shallow aquifer below the tailing's facilities creating a hydraulic barrier.

The unnamed tributary below the tailings in the north could experience baseflow reduction of between 2 to 3 m³/day and is deemed negligible.

Scenario 2 – Abstraction from future/conceptual scavenger wells (Dewatering impact)

Abstraction from the scavenger wells:

- South deep scavenger wells - 2 513 m³/day to 3 000 m³/day and
- Doornpoort tailings scavenger wells - 3 344 m³/day to 4 000 m³/day
- Future scavenger well abstraction at 3 100 m³/day
- Total abstraction from all boreholes at 10 100 m³/day

The model indicates the predicted cones of depression, resulting from the scavenger wells. The scavenger wells are effectively dewatering the shallow aquifer below the tailing's facilities creating a hydraulic barrier.

The unnamed tributary below the tailings in the north could experience baseflow reduction of between 3 to 4 m³/day and is deemed negligible.

Scenario 3 – Contaminant plume without scavenger wells

This scenario simulated unmitigated plume movement of seepages from tailings likely to be acid rock drainage, high in total dissolved solids (2 000 - 4 000 mg/L), sulphate (800 - 2 800 mg/L), with sulphate use as conservative tracer. The plume expands at a rate of 20 to 30 m a year and dilutes at the plume front due to dilution with uncontaminated groundwater.

The average sulphate concentration entering the Leeuspruit is also expected to increase over time from approximately 500 mg/l during 2025 to 2800 mg/l in year 2050.

Scenario 4 – Contaminant plume with scavenger wells

This scenario simulated the plume with drilled scavenger wells as mitigation through hydraulic containment. It follows that there is a significant reduction in plume expansion with more than 40% of the plume captured through scavenger wells.

The average sulphate concentration entering the Leeuspruit is expected to decrease from approximately 2800 to 500mg/l in 2050. This confirms monitoring results in which scavenger wells are effective in abstracting contaminated groundwater from the aquifers, while the numerical groundwater flow and contaminant transport model show that the scavenger wells will be effective in containing the spread of the plume.

12 RECOMMENDATIONS

The following recommendations are put forward:

- Authorised abstraction volume of 3 686 544 m³/annum to align with modelled containment requirements. This is motivated as it is Category B medium scale abstraction operation.
- Maintain existing scavenger borehole network and pumping regime to ensure continued plume containment
- Physical monthly groundwater level measurements of abstraction boreholes. It is crucial to monitor the groundwater levels and volumes in response to abstraction. This is to ensure successful dewatering and collection of contact water moving through the subsurface.
- It is recommended to do a comprehensive quarterly analysis at an accredited laboratory for parameters pH, Electrical conductivity, total dissolved solids, major anions and cations (Ca, Mg, Na, NO₃, Cl, SO₄,) and metals Al, Fe, and Mn.
- It is recommended that proposed abstraction boreholes are pumped according to the recommended sustainable yield, and at the proposed pumping schedule of 24 hours of pumping per day.
- Reassess abstraction rates periodically based on observed drawdown and recharge trends.
- Update the model every second to evaluate dewatering impacts.

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Appendix A FC Sustainable Yields

Summary			Main	BH01							
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used		
☒	Basic FC	1.63	0.05	7906		395.3		3.30E-03	41.3	1.630878	
☒	Advanced FC	4.40		7906		395.3		1.00E-03	41.3		
☒	FC inflection point	0.26	0.09						4.1	0.261008	
☒	Cooper-Jacob	1.02	0.95			16.2		1.04E-06	41.3	1.021253	
☐	FC Non-Linear								40.0		
☐	Barker	0.00	0.78	K _f =	201	S _g =		1.00E-07	41.3		
Average Q _{sust} (l/s)		0.97	0.69	b =	0.20	Fractal dimension n =		2.02			
1.83											
Recommended abstraction rate (L/s)		0.97	for 24 hours per day							3.50 m ³ per hour = 83.90 m ³ per day	
Hours per day of pumping		12	1.37	L/s for 12 hours per day							4.94 m ³ per hour = 59.34 m ³ per day
Amount of water allowed to be abstracted per month		2516.953	m ³								
Borehole could satisfy the basic human need of		3356	persons								
Is the water suitable for domestic use (Yes/No)											

Summary			Main	SC31							
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used		
☒	Basic FC	0.34	0.01	3162		158.1		3.30E-03	41.3	0.341702	
☒	Advanced FC	0.92		3162		158.1		1.00E-03	41.3		
☒	FC inflection point	0.13	0.03						6.3	0.133124	
☒	Cooper-Jacob	0.14	0.13			1.1		1.25E-01	41.3	0.136485	
☐	FC Non-Linear								40.0		
☐	Barker	0.00	1.61	K _f =	201	S _g =		1.00E-07	41.3		
Average Q _{sust} (l/s)		0.20	0.12	b =	0.20	Fractal dimension n =		2.02			
0.38											
Recommended abstraction rate (L/s)		0.20	for 24 hours per day							0.73 m ³ per hour = 17.61 m ³ per day	
Hours per day of pumping		12	0.29	L/s for 12 hours per day							1.04 m ³ per hour = 12.45 m ³ per day
Amount of water allowed to be abstracted per month		528.1561	m ³								
Borehole could satisfy the basic human need of		704	persons								
Is the water suitable for domestic use (Yes/No)											

Summary			Main	SC43							
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used		
☒	Basic FC	7.74	0.07	126490		6324.5		1.65E-03	41.3	7.736512	
☒	Advanced FC	20.63		126490		6324.5		1.00E-03	41.3		
☒	FC inflection point	6.46	0.87						14.0	6.461853	
☒	Cooper-Jacob	8.10	7.57			106.8		2.31E-09	41.3	8.102658	
☐	FC Non-Linear								40.0		
☐	Barker	0.00	0.06	K _f =	201	S _g =		1.00E-07	41.3		
Average Q _{sust} (l/s)		7.43	0.86	b =	0.20	Fractal dimension n =		2.02			
10.73											
Recommended abstraction rate (L/s)		7.43	for 24 hours per day							26.76 m ³ per hour = 642.27 m ³ per day	
Hours per day of pumping		12	10.51	L/s for 12 hours per day							37.85 m ³ per hour = 454.24 m ³ per day
Amount of water allowed to be abstracted per month		19268.09	m ³								
Borehole could satisfy the basic human need of		25691	persons								
Is the water suitable for domestic use (Yes/No)											

Summary			Main	SC45							
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used		
☒	Basic FC	3.18	0.06	23717		1185.8		3.30E-03	41.3	3.17605	
☒	Advanced FC	8.51		23717		1185.8		1.00E-03	41.3		
☒	FC inflection point	0.97	0.24						6.5	0.968941	
☒	Cooper-Jacob	2.66	2.49			195.8		1.28E-51	41.3	2.660553	
☐	FC Non-Linear								40.0		
☐	Barker	0.00	0.28	K _f =	201	S _g =		1.00E-07	41.3		
Average Q _{sust} (l/s)		2.27	1.15	b =	0.20	Fractal dimension n =		2.02			
3.83											
Recommended abstraction rate (L/s)		2.27	for 24 hours per day							8.17 m ³ per hour = 196.00 m ³ per day	
Hours per day of pumping		12	3.21	L/s for 12 hours per day							11.55 m ³ per hour = 138.62 m ³ per day
Amount of water allowed to be abstracted per month		5879.99	m ³								
Borehole could satisfy the basic human need of		7840	persons								
Is the water suitable for domestic use (Yes/No)											

Summary		Main		SC46							
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used		
☒	Basic FC	0.71	0.01	7906		395.3		3.30E-03	41.3	0.708062	
☒	Advanced FC	1.90		7906		395.3		1.00E-03	41.3		
☒	FC inflection point	0.36	0.07						9.5	0.358426	
☒	Cooper-Jacob	0.51	0.47			12.9		2.23E-14	41.3	0.507953	
☐	FC Non-Linear								40.0		
☐	Barker	0.00	0.79	K _f =	201		S _s =	1.00E-07	41.3		
	Average Q _{sust} (l/s)	0.52	0.18	b =	0.20	Fractal dimension n =		2.02			
0.87											
Recommended abstraction rate (L/s)		0.52	for 24 hours per day					1.89 m ³ per hour =		45.34 m ³ per day	
Hours per day of pumping		12	0.74	L/s for 12 hours per day					2.67 m ³ per hour =		32.07 m ³ per day
Amount of water allowed to be abstracted per month		1360.317	m ³								
Borehole could satisfy the basic human need of		1814	persons								
Is the water suitable for domestic use (Yes/No)											

Summary		Main		SC49							
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used		
☒	Basic FC	1.16	0.02	11068		553.4		3.30E-03	41.3	1.160276	
☒	Advanced FC	3.11		11068		553.4		1.00E-03	41.3		
☒	FC inflection point	0.49	0.10						8.8	0.494087	
☒	Cooper-Jacob	0.89	0.84			43.1		4.86E-32	41.3	0.894654	
☐	FC Non-Linear								40.0		
☐	Barker	0.00	0.58	K _f =	201		S _s =	1.00E-07	41.3		
	Average Q _{sust} (l/s)	0.85	0.34	b =	0.20	Fractal dimension n =		2.02			
1.41											
Recommended abstraction rate (L/s)		0.85	for 24 hours per day					3.06 m ³ per hour =		73.41 m ³ per day	
Hours per day of pumping		12	1.20	L/s for 12 hours per day					4.33 m ³ per hour =		51.92 m ³ per day
Amount of water allowed to be abstracted per month		2202.351	m ³								
Borehole could satisfy the basic human need of		2936	persons								
Is the water suitable for domestic use (Yes/No)											

Summary		Main		SC50							
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used		
☒	Basic FC	1.00	0.02	7906		395.3		3.30E-03	41.3	1.002955	
☒	Advanced FC	2.69		7906		395.3		1.00E-03	41.3		
☒	FC inflection point	0.31	0.08						6.0	0.312199	
☒	Cooper-Jacob	0.59	0.55			7.7		6.89E-05	41.3	0.588638	
☐	FC Non-Linear								40.0		
☐	Barker	0.00	0.78	K _f =	201		S _s =	1.00E-07	41.3		
	Average Q _{sust} (l/s)	0.63	0.35	b =	0.20	Fractal dimension n =		2.02			
1.15											
Recommended abstraction rate (L/s)		0.63	for 24 hours per day					2.28 m ³ per hour =		54.83 m ³ per day	
Hours per day of pumping		12	0.90	L/s for 12 hours per day					3.23 m ³ per hour =		38.78 m ³ per day
Amount of water allowed to be abstracted per month		1644.876	m ³								
Borehole could satisfy the basic human need of		2193	persons								
Is the water suitable for domestic use (Yes/No)											

Summary		Main		SC51							
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used		
☒	Basic FC	0.59	0.01	5534		276.7		3.30E-03	41.3	0.590581	
☒	Advanced FC	1.58		5534		276.7		1.00E-03	41.3		
☒	FC inflection point	0.24	0.05						8.0	0.243508	
☒	Cooper-Jacob	0.49	0.46			53.4		7.04E-81	41.3	0.487397	
☐	FC Non-Linear								40.0		
☐	Barker	0.00	1.05	K _f =	201		S _s =	1.00E-07	41.3		
	Average Q _{sust} (l/s)	0.44	0.18	b =	0.20	Fractal dimension n =		2.02			
0.73											
Recommended abstraction rate (L/s)		0.44	for 24 hours per day					1.59 m ³ per hour =		38.06 m ³ per day	
Hours per day of pumping		12	0.62	L/s for 12 hours per day					2.24 m ³ per hour =		26.92 m ³ per day
Amount of water allowed to be abstracted per month		1141.763	m ³								
Borehole could satisfy the basic human need of		1522	persons								
Is the water suitable for domestic use (Yes/No)											

Summary			Main	SC59						
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used	
☒	Basic FC	1.96	0.03	22136		1106.8		3.30E-03	41.3	1.961358
☒	Advanced FC	5.24		22136		1106.8		1.00E-03	41.3	
☒	FC inflection point	0.99	0.20						9.0	0.985959
☒	Cooper-Jacob	1.12	1.05			14.1		3.23E-04	41.3	1.119476
☐	FC Non-Linear								40.0	
☐	Barker	0.00	0.30	K _f =	201	S _s =		1.00E-07	41.3	
Average Q _{sust} (l/s)		1.36	0.53	b =	0.20	Fractal dimension n =		2.02		
2.33										
Recommended abstraction rate (L/s)				1.36				for 24 hours per day		4.88 m ³ per hour = 117.12 m ³ per day
Hours per day of pumping				12				1.92 L/s for 12 hours per day		6.90 m ³ per hour = 82.83 m ³ per day
Amount of water allowed to be abstracted per month				3513.709				m ³		
Borehole could satisfy the basic human need of				4685				persons		
Is the water suitable for domestic use (Yes/No)										

Summary			Main	SC60					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used
☒	Basic FC	1.37	0.01	22136		1106.8		3.30E-03	41.3
☒	Advanced FC	3.66		22136		1106.8		1.00E-03	41.3
☒	FC inflection point	1.10	0.16						14.0
☒	Cooper-Jacob	1.04	0.98			44.2		2.14E-27	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.30	K _f =	201	S _s =		1.00E-07	41.3
Average Q _{sust} (l/s)		1.17	0.17	b =	0.20	Fractal dimension n =		2.02	
1.79									
Recommended abstraction rate (L/s)				1.17				for 24 hours per day	
Hours per day of pumping				12				1.66 L/s for 12 hours per day	
Amount of water allowed to be abstracted per month				3035.667				m ³	
Borehole could satisfy the basic human need of				4048				persons	
Is the water suitable for domestic use (Yes/No)									

1.370205

1.09869

1.044608

4.22 m³ per hour = 101.19 m³ per day

5.96 m³ per hour = 71.56 m³ per day

Summary			Main	SC61					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used
☒	Basic FC	6.24	0.09	67988		3399.4		1.65E-03	41.3
☒	Advanced FC	16.67		67988		3399.4		1.00E-03	41.3
☒	FC inflection point	3.17	0.58						9.9
☒	Cooper-Jacob	4.29	4.01			329.7		2.56E-45	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.10	K _f =	201	S _s =		1.00E-07	41.3
Average Q _{sust} (l/s)		4.57	1.55	b =	0.20	Fractal dimension n =		2.02	
7.59									
Recommended abstraction rate (L/s)				4.57				for 24 hours per day	
Hours per day of pumping				12				6.46 L/s for 12 hours per day	
								16.43 m ³ per hour = 394.43 m ³ per day	
								23.25 m ³ per hour = 278.96 m ³ per day	
Amount of water allowed to be abstracted per month				11833.02				m ³	
Borehole could satisfy the basic human need of				15777				persons	
Is the water suitable for domestic use (Yes/No)									

Summary			Main	SC65					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used
☒	Basic FC	2.62	0.04	25298		1264.9		3.30E-03	41.3
☒	Advanced FC	7.01		25298		1264.9		1.00E-03	41.3
☒	FC inflection point	1.15	0.22						9.0
☒	Cooper-Jacob	1.96	1.83			85.0		5.96E-28	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.27	K _f =	201	S _g =		1.00E-07	41.3
Average Q _{sust} (l/s)		1.91	0.74	b =	0.20	Fractal dimension n =		2.02	
3.18									
Recommended abstraction rate (L/s)				1.91				for 24 hours per day	
Hours per day of pumping				12				2.70 L/s for 12 hours per day	
Amount of water allowed to be abstracted per month				4949.882				m ³	
Borehole could satisfy the basic human need of				6600				persons	

2.620316

1.150647

1.958067

6.87 m³ per hour = 165.00 m³ per day

9.72 m³ per hour = 116.69 m³ per day

Summary			Main	SC82					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m²/d)		Late T (m²/d)		S	AD used
☒	Basic FC	4.60	0.07	47434		2371.7		3.30E-03	41.3
☒	Advanced FC	12.30		47434		2371.7		1.00E-03	41.3
☒	FC inflection point	2.16	0.42						9.0
☒	Cooper-Jacob	3.30	3.09			90.4		3.89E-15	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.15	K _f =	201	S _b =	1.00E-07	41.3	
Average Q _{sust} (l/s)		3.35	1.22	b =	0.20	Fractal dimension n =		2.02	
5.59									
Recommended abstraction rate (L/s)		3.35	for 24 hours per day				12.08 m³ per hour = 289.86 m³ per day		
Hours per day of pumping		12	4.75	L/s for 12		hours per day		17.08 m³ per hour = 205.00 m³ per day	
Amount of water allowed to be abstracted per month		8695.699	m³						
Borehole could satisfy the basic human need of		11594	persons						

Summary			Main	SC84						
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m²/d)		Late T (m²/d)		S	AD used	
☒	Basic FC	6.27	0.08	79056		3952.8		1.65E-03	41.3	6.271347
☒	Advanced FC	16.74		79056		3952.8		1.00E-03	41.3	
☒	FC inflection point	3.80	0.63						11.0	3.802152
☒	Cooper-Jacob	3.94	3.68			66.5		6.32E-07	41.3	
☐	FC Non-Linear								40.0	3.940696
☐	Barker	0.00	0.09	K _f =	201	S _s =		1.00E-07	41.3	
Average Q _{sust} (l/s)		4.67	1.39	b =	0.20	Fractal dimension n =		2.02		
7.69										
Recommended abstraction rate (L/s)		4.67		for 24 hours per day					16.82 m³ per hour = 403.61 m³ per day	
Hours per day of pumping		12		6.61		L/s for 12 hours per day			23.79 m³ per hour = 285.45 m³ per day	
Amount of water allowed to be abstracted per month		12108.26		m³						
Borehole could satisfy the basic human need of		16144		persons						
Is the water suitable for domestic use (Yes/No)										

Summary			Main	SDS04					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m²/d)		Late T (m²/d)		S	AD used
☒	Basic FC	0.79	0.01	11068		553.4		3.30E-03	41.3
☒	Advanced FC	2.12		11068		553.4		1.00E-03	41.3
☒	FC inflection point	0.50	0.10						9.5
☒	Cooper-Jacob	0.43	0.41			5.0		8.09E-04	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.58	K _f =	201	S _a =		1.00E-07	41.3
Average Q _{sust} (l/s)		0.58	0.19	b =	0.20	Fractal dimension n =		2.02	
0.96									
Recommended abstraction rate (L/s)		0.58		for 24 hours per day				2.07 m³ per hour = 49.73 m³ per day	
Hours per day of pumping		12		0.81		L/s for 12 hours per day		2.93 m³ per hour = 35.17 m³ per day	
Amount of water allowed to be abstracted per month		1491.878		m³					
Borehole could satisfy the basic human need of		1989		persons					
Is the water suitable for domestic use (Yes/No)									

Summary			Main	SDS06							
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m²/d)		Late T (m²/d)		S	AD used		
☒	Basic FC	8.25	0.21	47434		2371.7		3.30E-03	41.3		
☒	Advanced FC	22.13		47434		2371.7		1.00E-03	41.3		
☒	FC inflection point	1.71	0.51						4.5		
☒	Cooper-Jacob	4.53	4.24			53.7		5.09E-03	41.3		
☐	FC Non-Linear								40.0		
☐	Barker	0.00	0.15	K _f =	201	S _a =		1.00E-07	41.3		
Average Q _{sust} (l/s)		4.83	3.28	b =	0.20	Fractal dimension n =		2.02			
9.15											
Recommended abstraction rate (L/s)			4.83	for 24 hours per day					17.38 m³ per hour =	417.24 m³ per day	
Hours per day of pumping			12	6.83	L/s for 12 hours per day					24.59 m³ per hour =	295.09 m³ per day
Amount of water allowed to be abstracted per month			12517.12	m³							
Borehole could satisfy the basic human need of			16689	persons							
Is the water suitable for domestic use (Yes/No)											

Summary			Main	SDS07					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m²/d)		Late T (m²/d)		S	AD used
☒	Basic FC	4.76	0.05	63245		3162.2		3.30E-03	41.3
☒	Advanced FC	12.71		63245		3162.2		1.00E-03	41.3
☒	FC inflection point	3.01	0.52						11.0
☒	Cooper-Jacob	3.37	3.15			82.5		6.66E-13	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.11	K _r =	201	S _s =	1.00E-07	41.3	
Average Q _{sust} (l/s)		3.71	0.93	b =	0.20	Fractal dimension n =		2.02	
5.96									
Recommended abstraction rate (L/s)			3.71	for 24 hours per day					13.36 m³ per hour = 320.72 m³ per day
Hours per day of pumping			12	5.25	L/s for 12 hours per day				18.90 m³ per hour = 226.82 m³ per day
Amount of water allowed to be abstracted per month			9621.487	m³					
Borehole could satisfy the basic human need of			12829	persons					
Is the water suitable for domestic use (Yes/No)									

Summary				Main	SDS08				
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m²/d)		Late T (m²/d)		S	AD used
☒	Basic FC	10.27	0.22	71150		3557.5		1.65E-03	41.3
☒	Advanced FC	27.49		71150		3557.5		1.00E-03	41.3
☒	FC inflection point	2.75	0.74						6.0
☒	Cooper-Jacob	7.13	6.66			165.9		1.24E-11	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.10	K _r =	201	S _s =	1.00E-07	41.3	
Average Q _{sust} (l/s)		6.71	3.78	b =	0.20	Fractal dimension n =		2.02	
11.91									
Recommended abstraction rate (L/s)				6.71		for 24 hours per day			
Hours per day of pumping				12		9.50		L/s for 12 hours per day	
								24.17 m³ per hour = 580.13 m³ per day	
								34.19 m³ per hour = 410.29 m³ per day	
Amount of water allowed to be abstracted per month				17403.95		m³			
Borehole could satisfy the basic human need of				23205		persons			
Is the water suitable for domestic use (Yes/No)									

Summary			Main	SDS17					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m²/d)		Late T (m²/d)		S	AD used
☒	Basic FC	2.95	0.03	47434		2371.7		1.65E-03	41.3
☒	Advanced FC	7.86		47434		2371.7		1.00E-03	41.3
☒	FC inflection point	2.37	0.35						13.5
☒	Cooper-Jacob	1.92	1.80			33.3		1.39E-07	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.15	K _r =	201	S _s =	1.00E-07	41.3	
Average Q _{sust} (l/s)		2.41	0.51	b =	0.20	Fractal dimension n =		2.02	
3.78									
Recommended abstraction rate (L/s)			2.41	for 24 hours per day					8.69 m³ per hour = 208.57 m³ per day
Hours per day of pumping			12	3.41	L/s for 12 hours per day			12.29 m³ per hour = 147.51 m³ per day	
Amount of water allowed to be abstracted per month			6257.023	m³					
Borehole could satisfy the basic human need of			8343	persons					
Is the water suitable for domestic use (Yes/No)									

Summary			Main	SDS18					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m²/d)		Late T (m²/d)		S	AD used
☒	Basic FC	6.21	0.09	63245		3162.2		3.30E-03	41.3
☒	Advanced FC	16.59		63245		3162.2		1.00E-03	41.3
☒	FC inflection point	2.61	0.63						6.5
☒	Cooper-Jacob	3.08	2.88			30.4		1.09E-01	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.11	K _r =	201	S _g =		1.00E-07	41.3
Average Q _{sust} (l/s)		3.97	1.96	b =	0.20	Fractal dimension n =		2.02	
7.12									
Recommended abstraction rate (L/s)		3.97	for 24 hours per day						
Hours per day of pumping		12	5.61	L/s for 12		hours per day		14.28 m³ per hour = 342.72 m³ per day 20.20 m³ per hour = 242.39 m³ per day	
Amount of water allowed to be abstracted per month			10281.71	m³					
Borehole could satisfy the basic human need of			13709	persons					
Is the water suitable for domestic use (Yes/No)									

Summary			Main	SPD01					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used
☒	Basic FC	1.72	0.02	20080		1004.0		1.65E-03	41.3
☒	Advanced FC	4.59		20080		1004.0		1.00E-03	41.3
☒	FC inflection point	0.90	0.18						9.5
☒	Cooper-Jacob	0.96	0.90			14.0		7.85E-06	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.33	K _f =	201	S _s =		1.00E-07	41.3
Average Q _{sust} (l/s)		1.19	0.46	b =	0.20	Fractal dimension n =		2.02	
2.04									
Recommended abstraction rate (L/s)				1.19		for 24 hours per day		4.29 m ³ per hour = 102.97 m ³ per day	
Hours per day of pumping				12		1.69 L/s for 12		hours per day 6.07 m ³ per hour = 72.83 m ³ per day	
Amount of water allowed to be abstracted per month				3089.214		m ³			
Borehole could satisfy the basic human need of				4119		persons			
Is the water suitable for domestic use (Yes/No)									

Summary			Main	SPD02					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used
☒	Basic FC	1.44	0.01	31622		1581.1		1.65E-03	41.3
☒	Advanced FC	3.85		31622		1581.1		1.00E-03	41.3
☒	FC inflection point	1.67	0.19						19.0
☒	Cooper-Jacob	1.06	0.99			31.4		1.67E-17	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.22	K _f =	201	S _s =		1.00E-07	41.3
Average Q _{sust} (l/s)		1.39	0.31	b =	0.20	Fractal dimension n =		2.02	
2.01									
Recommended abstraction rate (L/s)				1.39		for 24 hours per day		5.01 m ³ per hour = 120.22 m ³ per day	
Hours per day of pumping				12		1.97 L/s for 12		hours per day 7.09 m ³ per hour = 85.03 m ³ per day	
Amount of water allowed to be abstracted per month				3606.728		m ³			
Borehole could satisfy the basic human need of				4809		persons			
Is the water suitable for domestic use (Yes/No)									

Summary			Main	SPD04					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m ² /d)		Late T (m ² /d)		S	AD used
☒	Basic FC	1.71	0.01	50596		2529.8		3.30E-03	41.3
☒	Advanced FC	4.55		50596		2529.8		1.00E-03	41.3
☒	FC inflection point	2.82	0.24						26.0
☒	Cooper-Jacob	1.17	1.09			25.6		2.26E-11	41.3
☐	FC Non-Linear								40.0
☐	Barker	0.00	0.14	K _f =	201	S _s =		1.00E-07	41.3
Average Q _{sust} (l/s)		1.90	0.84	b =	0.20	Fractal dimension n =		2.02	
2.56									
Recommended abstraction rate (L/s)				1.90		for 24 hours per day		6.82 m ³ per hour = 163.79 m ³ per day	
Hours per day of pumping				12		2.68 L/s for 12		hours per day 9.65 m ³ per hour = 115.84 m ³ per day	
Amount of water allowed to be abstracted per month				4913.754		m ³			
Borehole could satisfy the basic human need of				6552		persons			
Is the water suitable for domestic use (Yes/No)									

Appendix B DRASTIC Method

DRASTIC parameters	Range	Rating (<i>r</i>)	Weight (<i>w</i>)
Water table depth (m)	0.0–1.5	10	5
	1.5–4.6	9	
	4.6–9.1	7	
	9.1–15.2	5	
	15.2–22.9	3	
	22.9–30.5	2	
	> 30.5	1	
Net recharge	11–13	10	4
	9–11	8	
	7–9	5	
	5–7	3	
	3–5	1	
Aquifer media	Rubble and sand	0	3
	Gravel and sand	7	
	Gravel, sand, clay, and silt	5	
	Sand and clay	4	
	Sand, clay, and silt	3	
Soil media	Rubble, sand, clay, and silt	9	2
	Gravel and sand	7	
	Gravel, sand, clay, and silt	6	
	Sand	5	
	Sand, clay, and silt	3	
	Clay and silt	2	
Topography or slope (%)	0–2	10	1
	2–6	9	
	6–12	5	
	12–18	3	
	> 18	1	
The impact of the vadose zone	Rubble, sand, clay, and silt	9	5
	Gravel and sand	7	
	Gravel, sand, clay, and silt	5	
	Sand, clay, and silt	3	
Hydraulic conductivity (m d^{-1})	0–4.1	1	3
	4.1–12.2	2	
	12.2–28.5	4	
	28.5–40.7	6	
	40.7–81.5	8	

